TELESCOPE MAKING 25

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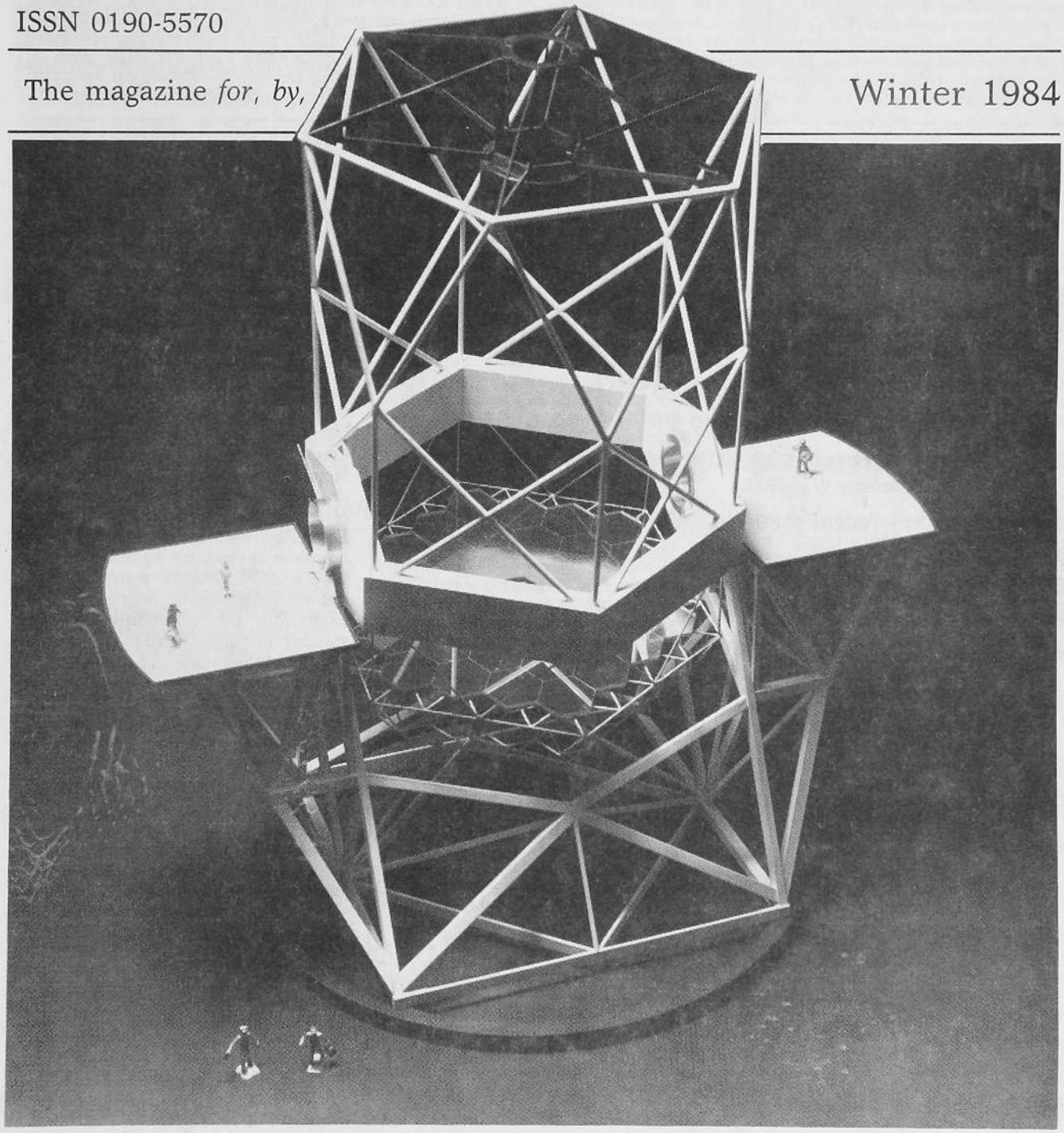

TELESCOPE MAKING

The magazine *for, by,* and *about* telescope makers!

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TM #25 may be late — but here it is. At last! There are two major reasons for this. As you may already know, AstroMedia has been sold to the Kalmbach Publishing Co., a Milwaukee-based hobby magazine company. In addition to *Trains, Model Railroader,* and *FineScale Modeller*, Kalmbach publishes and/or distributes numerous magazines, books, and booklets about airplanes, ships, models, tanks — and now *Telescope Making*. Keep a watch on the hobby store magazine racks. Anyhow, the sale and its side-effects have consumed considerable chunks of my time and energy. The other late-making factor is Halley's comet, or more precisely, AstroMedia's forthcoming *Halley's Comet*. While ASTRONOMY's Frank Reddy wrote the text of the book, I ended up picking up most of his regular ASTRONOMY work for three months. I also became quite involved in expanding the capabilities of the starchart plotting computer programs — which did their thing and produced not only the detailed horizon charts for the comet book, but also did the base map for AstroMedia's *Return of Halley's Comet* wall chart. Altogether, this book and chart offer the general public more specific and detailed observing information than they will find anywhere else. (If it comes out as well as it looks like it will, then buy a copy when you see it at your local bookseller.)

So — my apologies to those of you who worried that something dire had happened to TM or to your subscription to it. TM is alive and well in Milwaukee — and, to mix the metaphors mercilessly, after three months of sitting dead in the water, we're picking up steam again.

Richard Berry

Letters

Tube Air Conditioning

Dear Richard / Just a note you might want to add on my 16″ telescope. If you remember, at Riverside we talked about the ventilation fans near the mirror, and you suggested a fan at the back of the mirror cell which would pull air from around the mirror and exhaust it from the tube. Well, I installed such a fan (a small DC-powered fan obtained from Jerryco) — and by golly, you know, it works great!

Just as you thought, the fan creates an airflow that "straightens out" the random heat currents arising from the mirror and cell components. I run the fan while observing and adjust its speed via a control on my hand box so that no image vibration is introduced from the fan itself.

The improvement in image quality is quite dramatic. When the fan is turned on, stars transform from big "fuzzies" to smaller, harder data. Before, I had to wait till midnight or later for stellar Airy disks to show themselves at high power. Now the wait is much shorter.

Of course, the effect the fan has diminishes as the mirror and cell reach equilibrium with the air, but the process is quickened by the action of the fan. Of course the fan does nothing to improve seeing effects outside the immediate tube environment. However, I have found out that an awful lot of the poor seeing I used to complain about is no longer a problem!

Tom Osypowski
14448 Mandolin Way
Nevada City, CA 95959

Anybody Got a Big Mirror for Sale?

Dear Richard / I am beginning what's sure to become a decade-long project. I'm looking for a 20″ to 24″ mirror, preferably figured to about f/6. It would be nice if it had a hole bored into it for a Cassegrain focus. I am hoping one of TM's reader will either have or know of a mirror such as I have described.

Jeffrey L. Hunt
P.O. Box 7
North Aurora, IL 60542

Taking the Prize

Dear Mr. R.E. Cox / I just received TM#23, and naturally the first thing I read was your editorial on awards. It tied in beautifully with an experience I recently had at Stellafane '84. Having built a "Thompsonian" telescope (with ideas taken from the pages of TM and only minor changes) to take my 13″ mirror to TSP '84, I decided to put it on display at Stellafane. Many people hadn't seen the design in person and I thought they might enjoy it.

On Saturday morning I set up and then sat back to inhale the atmosphere that can only be found on the top of Breezy Hill. I had no intention of entering my scope in the awards competition — and steadfastly refused all urgings from fellow Stellafaners to do so. Eventually a group of judges found their way to my area and asked the Big Question I had been waiting for, "Why haven't you entered the competition?"

My answer was simply this: "There is no award that you can give me that can match the feeling of bringing a telescope of my own making to the top of Breezy Hill and displaying in the presence of the ghosts of all the people who have walked in this special place." Unlike some of the people whom I heard grumbling about their instruments not winning any awards, I went home Sunday morning with the biggest prize of all!

T.E. Lloyd
18 Strong St. Ext.
East Haven, CT 06512

A Chatty Letter

Dear Richard / It was nice to see you in Texas. I had a great time and hope to get back there — although things are a little iffy for next year. I was amused to see my name in your "convention" article in TM. I wish I had managed to get to Riverside, too.

Everyone here got a big kick out of seeing the picture of Roland wearing one of my "No-Schmidt-Cass" tee-shirts. I had a lot of fun with those shirts. I am making one for Norm Sperling and am very tempted to put "Beware of Speed Merchants" on the back — but I guess I'll resist. He didn't seem pleased when I mentioned the idea.

Stellafane was really great this year — although there were certainly a lot of worried people during Friday's monsoons. As you have no doubt heard, there were some excellent scopes this year. I took my 10″ f/9.5 up again and we had a great time observing with it Saturday night. The Veil was beautiful with a 26mm Tele-Vue and a premium Lumicon UHC filter. Both halves showed a lot of detail and NGC-6979 was obvious. M-27 was really nice; Mike Simmons counted 12 stars within the nebulosity.

I was impressed with Ken Fulton's *The Light-Hearted Astronomer*. Even though it's supposedly written for beginners, it had a lot to say to me — and I've heard other people who've been doing telescopes and astronomy for a while say the same thing. We have been recommending the book to everyone who has expressed an interest in buying a telescope.

I really get frustrated sometimes about all the lousy telescopes that not only cost people a fair amount of money but turn them off to astronomy. Our club gets lots of requests for help in buying a telescope. We discourage people from rushing out and getting something right away, and encourage them to read up on telescopes, talk to club members, and visit a couple of star parties. Frequently, though, people don't look around for an astronomy club until they've already bought the telescope ("Oh yes, I have a 454 power..."). There must be a lot more people who get lousy telescopes that we never hear from. I hate to think about the number of people who get turned off to astronomy because they were uninformed.

Alan French
335 Twelfth St.
Schenectady, NY 12306

— I didn't know those shirts came from you!

Mirrors for Malaysia

Dear Sir / With reference to the editorial in TM#22, just received, I am writing on behalf of the members of the Astronomical Society of Malaysia. Ours is a small society, only recently registered with the authorities here and most of our members are beginners in astronomy. Although they are keen, they lack experience and many are not well off financially.

Lack of experience can be met by our few older members who have built their own telescopes and are willing to help newcomers get a start. Lack of money is a problem, particularly for our members still at school or college, who represent about a quarter of our membership. We are concerned about maintaining their interest, as the future of the Society lies with them. Ownership of a self-built telescope is one good way of doing this.

Perhaps there are some of your readers who, having built a second or later telescope, have the optics from an earlier and usually smaller instrument, which they would be willing to donate to our Society. Any such optics would be passed on free to those of our members who give a firm undertaking to put them to good use.

Miss Tan Cheng Sim
Persatuan Astronomi Malaysia
The Astronomical Society of Malaysia
Secretariat
17Jalan SS 2/76
Petaling Jaya, Selangor

— Bob and I hope that TM's readers will respond to this request generously.

You CAN Take It With You!

Dear Richard / In TM#18's cover story, "You Can Take It With You," I described my 12-foot pre-fab observatory. Underlying its design philosophy was being able to dismantle and move the observatory. I am pleased to report that I have done just that — and the move went off without a hitch.

It took about a week to tear the building down and a month to re-erect it — considerably more work than anticipated, but vastly less than starting from scratch. It is now located on a remote rural hill 40 miles from the nearest city lights and 2000 feet higher in elevation. The difference is absolutely astounding! Deep-sky objects are breathtaking with subtle outer structure in galaxies and nebulae very apparent.

I now have a set of Coulter's 29-inch optics set in my garage and am about to pour the foundation for an 18-foot dome of similar construction. The mount will be a giant English yoke equatorial. Because of the scope and expense of this project, I expect it will take me a few years to complete. I'm in no great rush, since I have the "small" one to enjoy in the interim. I'll keep you posted on progress. Keep up the fine work.

Tom Dey
7989 Canadice Rd., Box 413
Springwater, NY 14560

9

The Eye
Your Window to the Universe

You may think that "window to the universe" is a rather fancy title to apply to a familiar structure in the human body. Then again, maybe it's not. The pupil itself is not even a real structure — it's just the opening in the ring of iris tissue. So the pupil is, in fact, a window: an opening through which radiant energy enters the eye.

The eye was not designed to be an astronomical instrument. When we use it as one, we simply press it into those duties. Its primary job is to alert the organism (that's you and me, folks) to make decisions that will allow continued well-being and life. But when we look at the stars or peer into a telescope, and the light from those distant sources falls on the retina — which, when stimulated, passes that message of stimulation to the brain — then that window is, indeed, a window to the universe.

As an astronomical instrument, the eye's three limiting factors are quite straightforward and easy to understand with a minimum of thought. Its short focal length creates small retinal imagery. The retinal image of the Moon (or any other subject having an angular diameter of ½°) is on the order of 0.01 inch across. In spite of this diminutive size, we still can detect detail of remarkable wealth — as naked eye maps of the Moon attest. Its limited aperture restricts the quantity of light reaching the retinal nerve receptors. Furthermore, the aperture is variable. Depending on a variety of conditions, it ranges from 2mm to 7mm in diameter. Its range of light-gathering ability is a factor of twelve, something under three stellar magnitudes.

The structure and purpose of the light-detecting retina fulfill one basic task: preserving the organism. There are two separate types of light receptors. One type, the cones, gathers in great numbers in that area of the retina responsible for fine acuity duties. In the central part of the retina — which we need for visual acuity and pointing vision, and which is called the macula and fovea centralis — there is an exclusive cone population.

Cones have the following properties: Each nerve ending has its own private pathway to the central nervous system, a sort of private telephone arrangement. This, coupled with their distribution, allows best visual acuity with a well-focused image. The cones are responsible for wavelength determination, a property resulting in the phenomenon of color vision. Finally, the cones are not very sensitive to incoming light, at least not when compared to the rods (which we'll cover next), and operate best under photopic conditions for daylight vision.

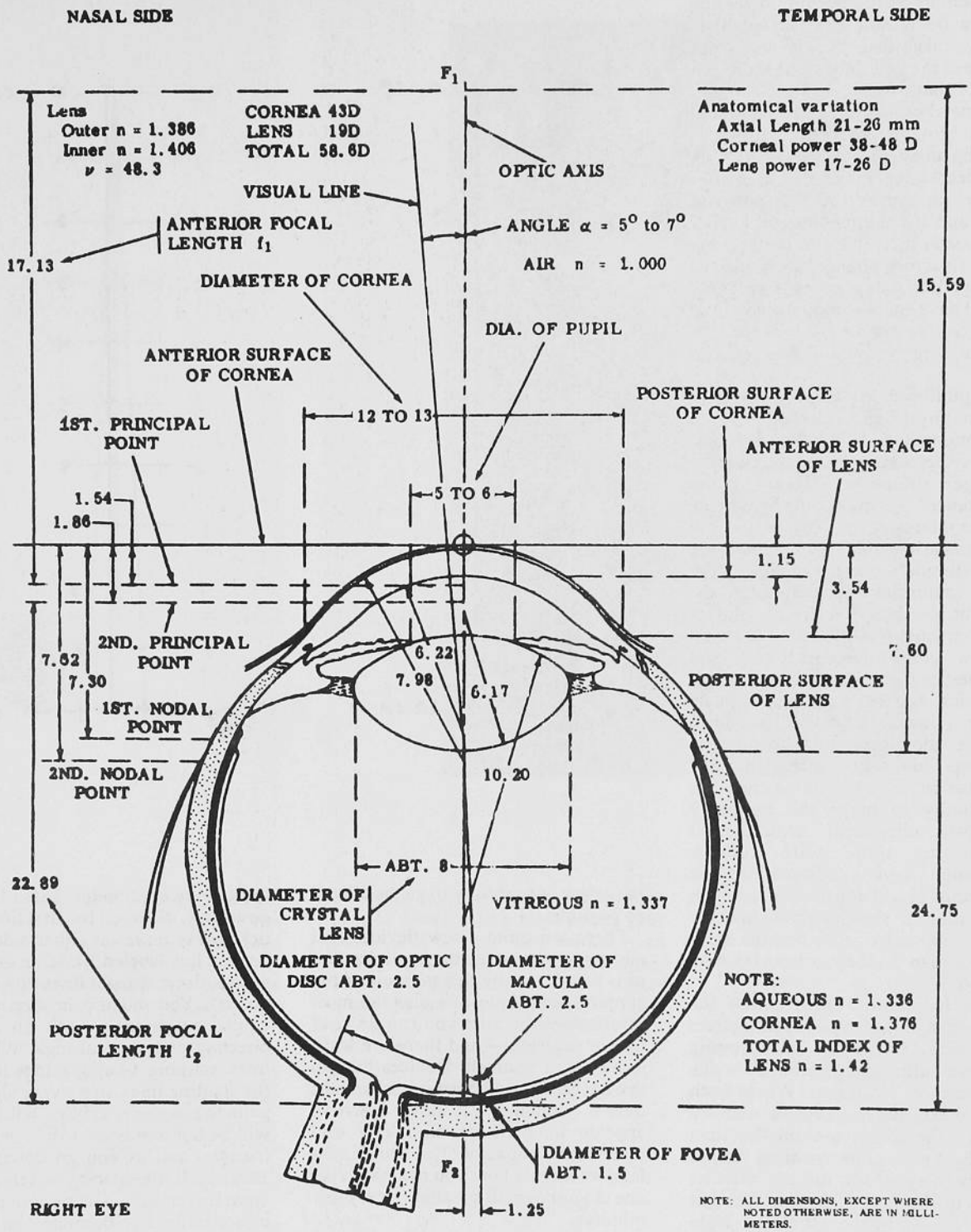
The other nerve endings are named rods, and whatever we have said about the cones, just the opposite is true for the rods: Multiple rod nerve endings are ganged to but a single carrier nerve to the CNS. This has a "party line" effect, and results in low-acuity ability for the rod structure. If one rod is stimulated by light, the message to the brain is as if all members of its group had been stimulated. Double stars with their individual messages falling on separate members of the cones are seen as double, while the same spacing falling on members of the gang of rods has its duality hidden because the message of their presence is carried to the brain by one fiber which is incapable of duality recognition. The rods are color blind; they see light without wavelength determination such as color vision. All this means the rods are capable of extreme sensitivity to low light levels. Because they inhabit mostly the peripheral part of the retina, our night vision is best in the peripheral fields.

The cones dominate the central portion of the retina, thin out toward the periphery where some, still identifiable as cones, now become ganged as are the rods. Where the cones begin to thin out, the rods replace them and themselves dominate the peripheral retina. We have, then, a dual retinal structure — an intermixture of nerve elements with differing properties. In general, you'll have to admit that they're excellent in life-saving decision-making situations, but not well suited to situations such as viewing the stars at night.

Unbelievable as it may sound, the eye is capable of working to protect the organism with light levels that range from one to ten billion! If the aperture variation of the pupil allows a retinal brightness variation on the order of twelve times, what is it that allows us to safely see under bright sunlight and reasonably well under full moonlight or less? The pupil's aperture isn't the answer. It is in the chemistry of the retina that we find the answer. We must hasten to add, though, that in any one condition or state, this enormous range is not possible. Its adaptability enables the visual apparatus to operate over a wide range of variations of light intensities.

It is the formation and destruction of chemicals bathing the retinal nerve endings — visual purple or rhodopsin — that allow the retina to operate successfully under scotopic conditions (of most interest to astronomers). With lots of light, rhodopsin bleaches out and retinal sensitivity decreases. The catalyst in this action of formation is vitamin A — the lack of which stops the formation of rhodopsin with the subsequent loss of night vision ability.

So, should it be of greater interest to astronomers to pay more attention to retinal health and chemistry integrity than the pupil? Well, not quite. The



optical train of the instrument, the telescope, must be properly arranged to make the system operate in the most efficient manner. The exit pupil must match the eye pupil size for best efficiency. So, let us say more about the pupil.

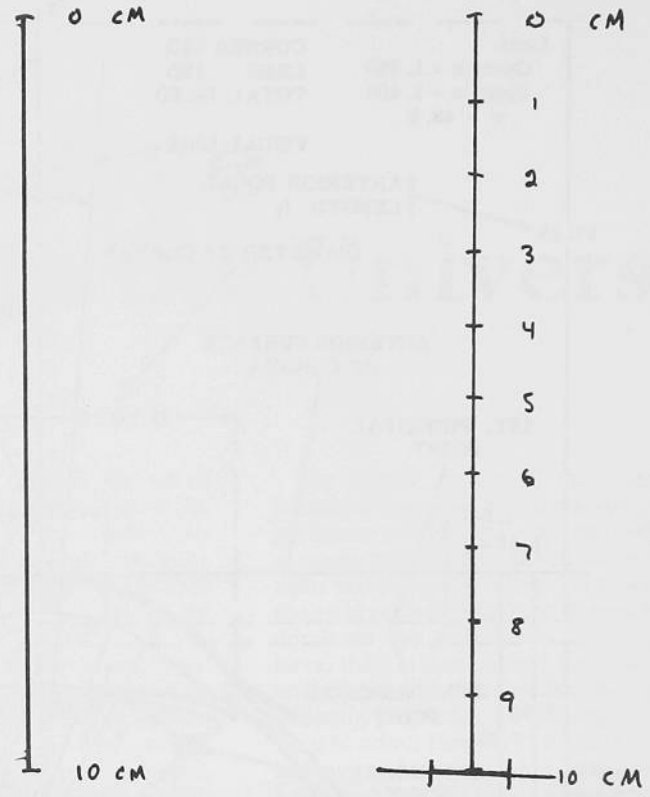
The following statement may come as a surprise to you, but hear me out. The eye has *three* pupil sizes to consider. They are: (1) The real pupil aperture. This would be the actual measured size of the opening created by the margins of the iris. It would be measured without the cornea in place, something not done anatomically unless you are using an incised eyeball for anatomical study. (2) The observed diameter as seen through the optical system of the cornea. This is called the virtual pupil; it is enlarged by the presence of the intervening refracting power of the steeply curved cornea, which averages 44.00 diopters of plus power magnification. The virtual, or entrance pupil as it is sometimes called, is seen by the outside measurer as larger than the real pupil. A pupil that is really 4mm in diameter will be measured as 4.5mm! (3) Finally, there is the pupil as viewed

from behind by the person possessing the eye being studied. This pupil is slightly magnified by the posterior surface of the lens and is called the exit pupil of that eye.

The newborn's eye has a small pupil which slowly enlarges with age, reaching an average of 4mm at age 20, then decreasing in size in and after middle age. By age 50, it's down to 3mm, and it continues to get smaller with greater age. This may well be due to iris structure changes as it stiffens with age. Most hyperopes (far-sighted people) have smaller pupils; myopes, or nearsighted people, have, on an average, larger pupils. But exceptions exist.

The pupil can be altered in diameter by light, physiological methods, as well as emotional means. Viewing a picture that gives pleasure dilates the pupil to a larger diameter. However, as astronomers, it is mainly the light reflex we are interested in. The reason the pupil constricts quickly in response to photo stimulation is not to control the actual amount of light that enters the eye, but to allow time for the slower acting chemistry of the retina to adjust to new conditions. In short, the quickness of the pupil response protects the retina and buys it time to make proper adjustment. If the light level increases slowly rather than quickly, the pupil does not make the fast response because the retina then has opportunity to make the necessary rhodopsin adjustment, something it cannot do alone with sudden application of photo stimulation. The formation of rhodopsin takes much longer then its bleaching out. In other words, it takes longer to become dark-adapted than it does to become day-adapted.

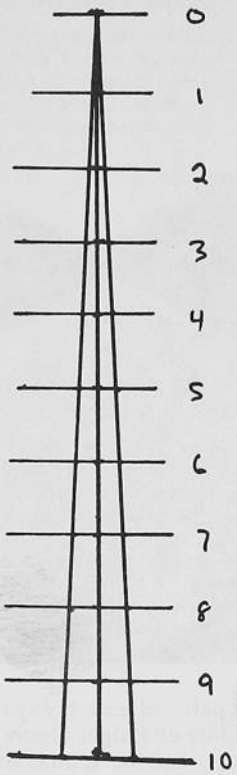
When light enters one eye only, the constriction of that pupil is called direct light reflex. However, light entering each eye influences the other — the pupillomotor influence. When both eyes are exposed to a certain intensity of light, the pupils are smaller than when light enters one eye alone. Try it. Close both eyes for a minute, then let light of medium intensity into the right eye only, keeping the left closed. Note the size of the pupil. Then open the left eye also, and you'll see the pupil constricting even more in the right eye, even though no more light is entering it than when it was open alone. This is a consensual reflex situation, also known as a bilateral or sympathetic reflex. It suggests, contrary to the advice in most observing guides, that we should be sure that the non-observing eye stays closed or patched to guarantee that the observing eye at the eyepiece has every opportunity to get as dilated as possible.

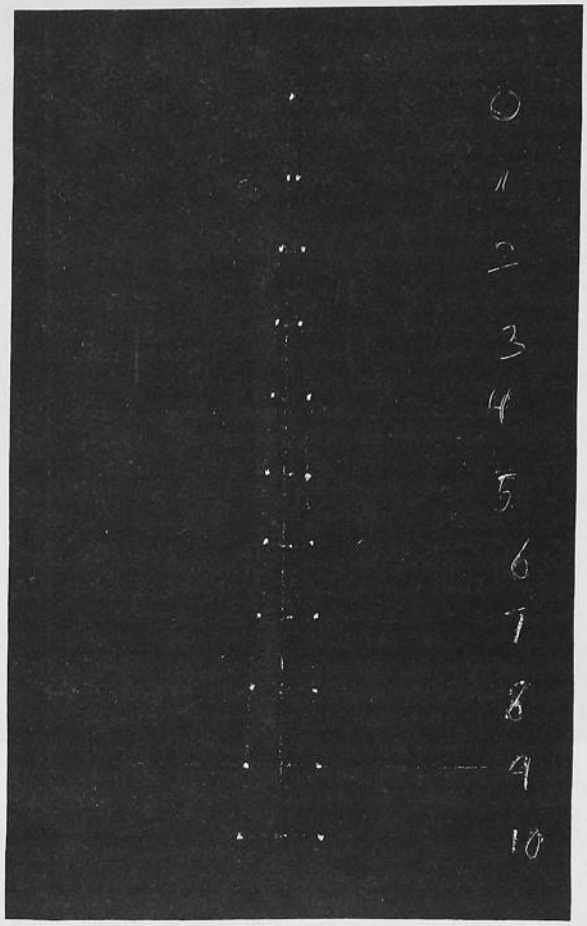


There are quite a few devices that allow you to measure the pupil size. But as is true for many things, some of the simplest techniques are also the most informative, because you can do your own measuring — and therefore learn more about yourself. Devices that do this are called pupillometers. Schlosser's device, which we'll now describe, appeals in both its simplicity and informative capacity. The sketch that follows reveals how you can construct one of your own in a matter of very few minutes.

Select a rather thin piece of stiff cardboard — black construction paper is preferred but not mandatory. A 4" x 6" piece of card stock works well, even if it's white. Obtain a millimeter scale at least 10cms long. Draw a vertical line the length of the long dimension of the card. About an inch from the end of the card, mark a point on the line. From this point, mark a line every centimeter for ten centimeters. With the rule placed at right angles to the first mark, draw short lines every centimeter. Label them 10 down to 0. Now, on the first line, place tick marks 5mm on either side of the vertical line labeled 10. From these two marks, draw straight lines down to the tick at 0. You will have created a skinny equilateral triangle with an altitude bisecting the top apical angle. Where the lines marking 1-cm spacings intersect the slanting lines, use a very sharp pin point to poke a series of pinholes. There will be but one hole at the apex of the triangle, and as you go down to the 10cm point, the spacing will increase in 1mm increments. The bottom pair will be separated by 10mm and be labeled 10.

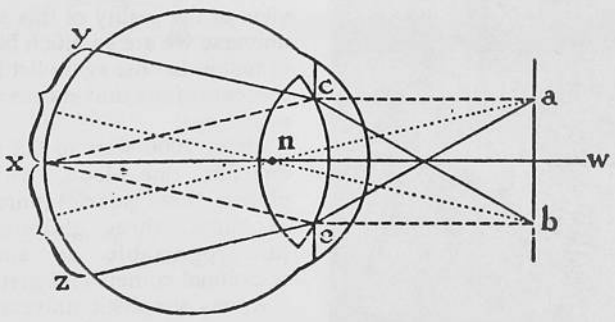
This simple gadget will allow you to measure your own pupil size. Hold the card close to your eye and look through the holes. Which holes allow the two blur circles you see to just touch? The number by that pair is the diameter of your pupil in millimeters. Of course, what you will really see will be one pair not touching, and the next set of holes overlapping. By some simple interpolation, you will be able to come up with





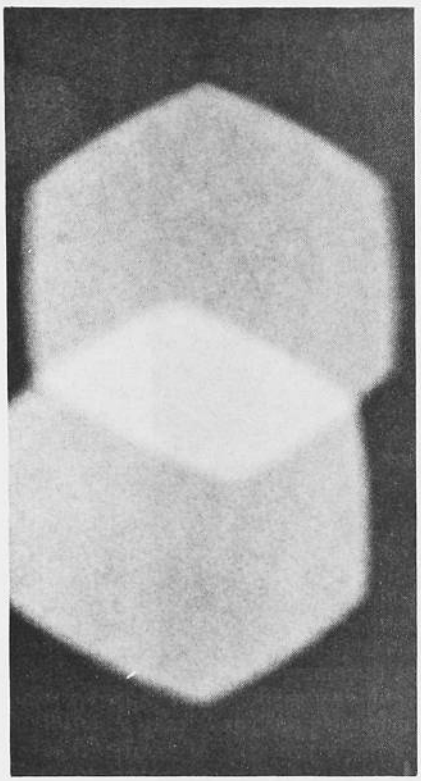
good estimates of the actual diameter.

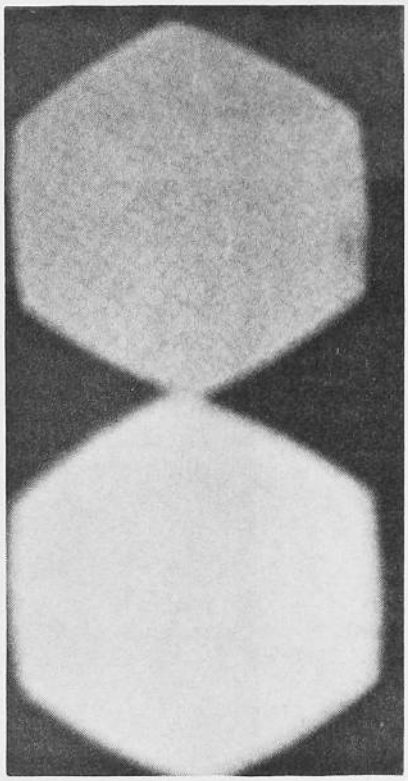
Now you can explore pupil size changes. When your eyes are first fixed at some optical infinity distance, such as the Moon and stars represent, the visual axes are parallel to each other. Note the pupil aperture. When your gaze is directed to a near point, your pupils will be seen to constrict — an action called an associated pupil reflex, because the same constriction occurs when the act of accommodation takes place to refocus from the far point to the near point. Reflex actions to the pupil size are created when the eyes are converged to a near subject point.

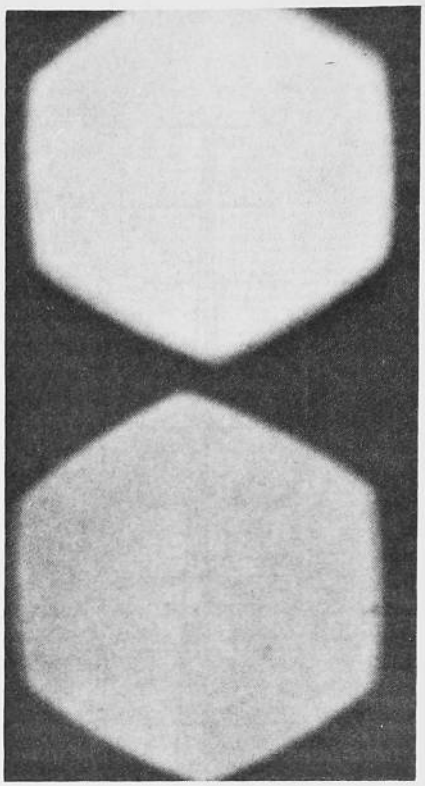


With prisms, it is possible to stimulate accommodation without convergence and the pupils still constrict. With lenses, it is possible to stimulate convergence without accommodation and again, the constriction takes place. When, in normal use of the eyes, accommodation and convergence take place at one and the same time, the pupils constrict in response to both actions. The neural pathway for the accommodative reflex is not the same path as for the photo-reflex action, the response to a bright light.

However, we in astronomy and observing are not as interested in constricting a pupil as we are in dilating it. Dilation may be produced by stimulating nearly any sensory nerve except the optic nerve. Stroking or pinching the skin of the neck generally has this dilating effect: this reflex is known as the cilio-spinal reflex or platysmal effect. Because severing of



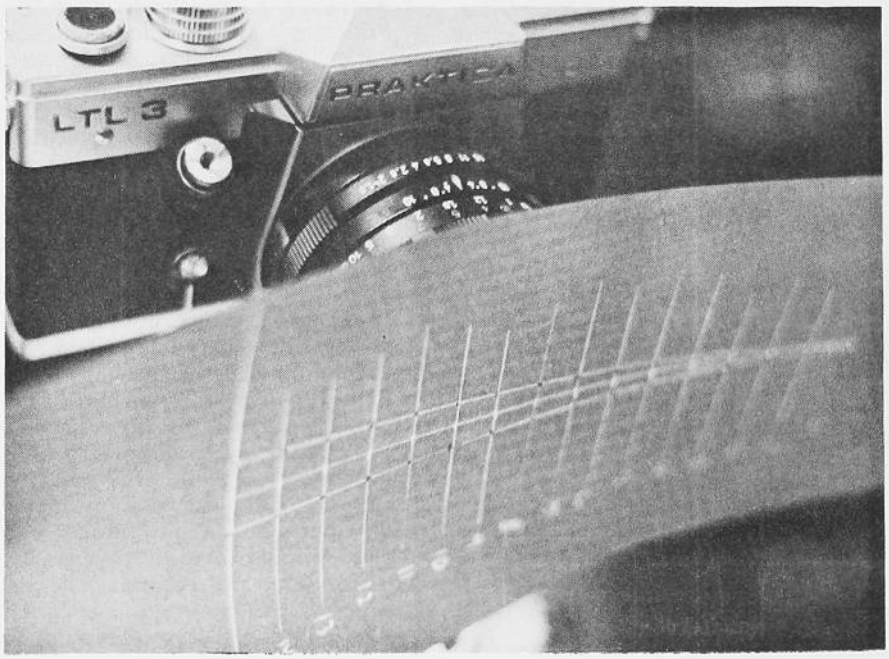




the cervical sympathetic nerve abolishes this reaction, the dilation cannot be ascribed, in its entirety, to inhibition of the pupil constricting center, and there must be active innervation and contraction of the radial muscle.

The sphincter (constricting) and radial (dilation) muscles are antagonistic muscles because the activity of the one opposes the activity of the other. This is a common arrangement in the body. Both action centers are constantly sending impulses, one center to the radial muscle and the other to the sphincter muscle. The size of the pupil is the sum of the contraction of the sphincter and radial muscles.

Consider night driving situations. The surrounding darkness stimulates the radials to dilate the pupil to allow light to reach the retina. Suddenly the bright lights of an approaching car enter the scene and also your eyes. The photo-reflex goes to work to allow time for the oversensitive retina — now flooded with rhodopsin chemistry to enhance irritability and night vision — to make changes, and the sphincters are over-stimulated. One set of conditions cries for dilation and the local bright spots creating a counter-reflex screaming to cut out the bright intrusion. And you wonder why night driving bothers people so much and creates that "drawing" sensation of discomfort? You may think a dark tint would negate some of that headlight brightness. True. But it would make the darkness darker — and the net effect is a disadvantage when there are no bright lights approaching. By the way, I do not recommend looking through a pupillometer while driving!



The aforementioned limitations of the human eye, used in an astronomical sense, allow us to perceive a limited view of the reality of this magnificent universe we are so much better aware of today. Let me again list for you the contents of the universe as seen by the naked eye:

About 7000 stars to 6.5 magnitude, one Sun, one Moon, five naked-eye planets, three galaxies (unrecognizable as such), three globular clusters (unrecognizable as such), plus occasional comets and meteors.

A very simplistic universe, actually.

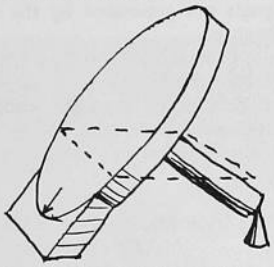
Sherman W. Schultz
Macalester College
Observatory-Planetarium
Physics and Astronomy Department
St. Paul, MN 55105

■

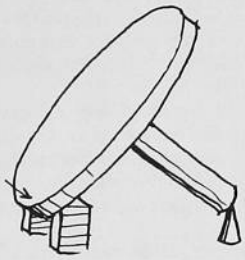
Letters

Conical Poncet Platform

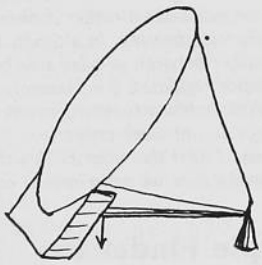
Dear Mr. Berry / I would like to bring to your readers' attention a new wrinkle in the Poncet mounting. This idea is so essential to "ideal" Poncet operation that we can surely assume it will be independently submitted by any number of people in the near future. Fig. 1 reviews the general Poncet concept:



take a useable equatorial mounting, chop off nonessential superstructure, and add a platform (dotted line). It also shows a typical bearing area, where weight results in a (desirable) downward force and an (undesirable) horizontal force (combined in the arrow indicated). In Fig. 2, in the classic Poncet bearing concept, the arrow again has



an undesirable horizontal component. The solution, a conical bearing area (Fig. 3), can be selected to generate a strictly vertical bearing force. The idea is simple in



retrospect, and I would not be surprised if you already have a stack of correspondence duplicating this suggestion.

Stephen B. Smith
Box 35
Sierra Vista, AZ 85636

— Builders: please take note. By the way, we do not have a stack of correspondence duplicating this suggestion.

Equatorial Help Wanted

Dear Sir / Approximately one year ago, I built a 12.5" f/6 Dobsonian in a cardboard tube. Although I have been very happy with it, obvious limitations exist and I would thus like to build some sort of conventional equatorial mount with a drive mechanism.

I have been a subscriber to your excellent magazine since 1983 and although I have read sections dealing with my proposed construction, nowhere have I seen an article as complete as the step-by-step details in "How to Build a Dobsonian."

Could you please advise me as to whether or not you have a step-by-step article, magazine, or book which explains how to build a conventional mount for a telescope of similar dimensions to my own and any information you may have about constructing a suitable motor drive.

My reasons for constructing my own mount and motor drive are twofold: 1) the expense and 2) a standard mount, counterweights and motor cost approximately $1,200 in Sydney!

Andrei L. Matiukevitch
11 Australia Street
Hurstville N.S.W.
Australia 2220

*— I understand your dilemma, but to the best of my knowledge there are no step-by-step directions for building a 12" equatorial reflector available in English. I have recently completed a book doing this for 4-inch, 6-inch, and 10-inch reflectors and a 6-inch refractor (*Build Your Own Telescope *will be published this fall). If any of TM's readers has advice or help for Mr. Matiukevitch, please write him!*

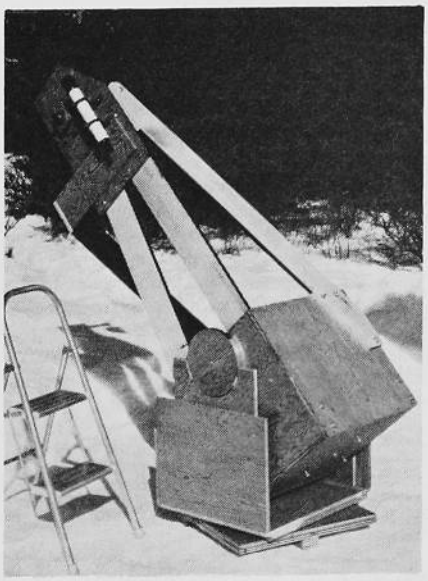
Genius Strikes Twice

Dear Richard / When I turned to the article in TM#19 by Dick Suiter and Tom Burns, "An Easy Design For a *Truly* Portable 17.5" Reflector," I thought I was seeing (and reading about) my own telescope. Faced with making a portable, collapsible telescope using Coulter's 17.5" optics, I independently came up with a design that is remarkably similar. The enclosed photographs show this similarity — right down to the baffling disk mounted on the Novak secondary holder! The one area of substantial difference in design is my omission of a front stiffening board for the mirror box. Surprisingly, rigidity does not seem to suffer.

Properly mounted and collimated, I have found Coulter's 17.5" optics to be excellent. Choice of eyepieces seems to be particularly important to reduce potential off-axis aberration. TeleVue's Plossls work well in this respect.

The concept of the binocular telescope has fascinated me for years. This last winter I finally did something about it. The accompanying photograph shows *my* idea of a perfect comet hunter (with all due respect to Celestron and the IRAS satellite). It is based on two 6" diameter f/5 primaries, elliptical secondaries, and star diagonals — thus each optical train requires three reflections. In spite of the rather crude method of aligning the telescopes (i.e., by shimming), it works very well.

Future work on this system (including a more sophisticated scheme for alignment) should include a simpler method for adjusting interpupilary distance. At present this is achieved by unclamping and sliding each eyepiece/star diagonal assembly into or



out from each telescope tube. It is important that the optical axis of the eyepieces remains parallel with the axis of the primary mirrors. In my scheme, the observer looks down toward the primaries of the binocular telescope. It would be interesting to see how others have implemented reflecting binocular telescope design.

Richard, thanks for the good work with *Telescope Making*. I thought it was all said and done — then came the Dobsonian Revolution, Poncet Mounts, computer designed eyepieces, etc., etc.!

Ronald B. Woodland
P.O. Box 105
Lindsey Hill Rd.
Worthington, MA 01098

— By now you will have seen Lee Cain's article in TM#20, too.

In Search of the Nitty-Gritty

Dear Richard / I just finished reading TM#23 and found it up to your usual high standards. Keep up the good work! This issue raised a few questions that I'd like to address:

First, I agree completely with Bob Cox about prizes at conventions. I rarely agree with the choices of judges at conventions that rate telescopes as first, second, third, and so on. Almost every instrument on display has something to offer — why hurt someone's feelings by giving a third prize when the point to giving prizes is to recognize the achievement? Ranked prizes are fine for the Olympics, but an ATM convention should be a cooperative effort to build better telescopes, not a competition.

Second, in your editorial you ask your readers if they think articles about large professional telescopes are appropriate. I think they are and I'd like to see more, providing the authors discuss the merits and drawbacks of the designs involved. A good technical discussion of mechanical, optical, or software design issues is appropriate no matter how large or small a telescope is used as the example.

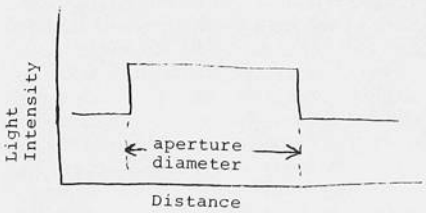
Letters

Unfortunately, the article on the British telescopes in the Canaries, besides being a little self-serving, did not get into the nitty-gritty of the optics or the reason they did things. I'd like to know more. Why did they choose an alt-az for the WHT? What engineering is simplified in doing so, and why? What penalties does an alt-az mount impose? What trade-offs did they make in the design of the optics? What problems are there in using such a fast primary mirror? Is the control system open-loop or closed-loop, and why? If questions like these are not addressed in large telescope articles in TM, they should be sent to publications not devoted to telescope making.

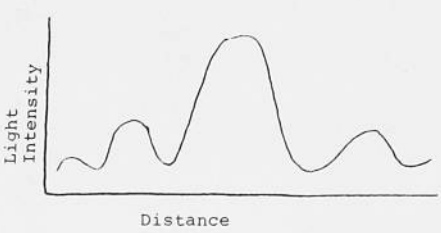
My third concern is the mistaken use of "Dobsonian" to describe all alt-azimuth telescopes. The caption for the photo of the alt-az binocular mount on page 28 of TM #23 describes the mount as Dobsonian. Where are the Teflon bearings? Where are the rocker side panels? Where is the sling for a thin mirror? John Dobson's contribution to amateur telescope is enormous — he has brought large optical telescopes to the masses at previously impossible prices. He has single-handedly revolutionized amateur telescope making. But let's give credit *only* where it is due.

Finally, I want to try to explain apodizing for those TM readers who have almost certainly been left behind by the discussion up to this point, and in particular, explain why the Gaussian distribution is desirable. When you look through any aperture, what is seen at the focal plane is the diffraction pattern of the aperture. The relation between the spatial distribution of light incident on the aperture and the spatial distribution of light at the focal plane is given by the Fourier transform. Instead of going into the mathematics of Fourier transforms, I will give the basic results that these transforms yield.

Suppose you have a circular aperture that is evenly illuminated. The spatial distribution of light incident on the aperture, in cross section, that actually enters the telescope looks like this:

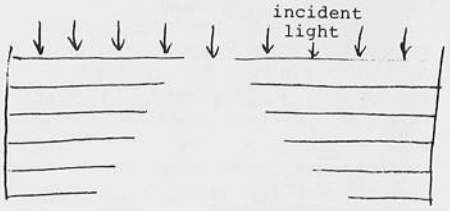


The Fourier transform of this function that is seen at the image plane looks like this:

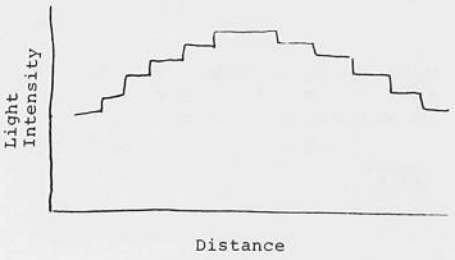


Looks familiar, doesn't it? It's the Airy ring pattern.

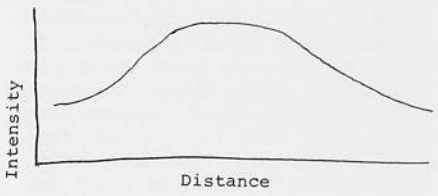
One form of apodizing is to use a sandwich of mesh screens, each screen having a larger hole than the previous one. An exploded view of the result may look like this:



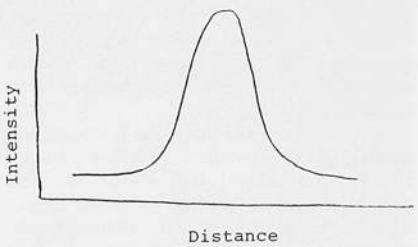
When squeezed together and placed over the normal telescope aperture, the screens make the light intensity distribution look like this:



This is a close approximation of a Gaussian distribution, which looks like this:



The mathematics of Fourier transforms is such that the Fourier transform of this Gaussian distribution looks like this:



— i.e., the Fourier transform of Gaussian distribution is another Gaussian distribution! Notice that there are no peaks or valleys outside the central peak. This means there are no rings. Unlike the Airy pattern, all the light goes into the central peak. By controlling the shape of the aperture apodizing curve, all the light from point sources can be confined to very small, bright, relatively sharply defined areas in the focal plane.

It is a peculiar property of Fourier transforms that the wider and more shallow the Gaussian curve at the aperture, the smaller and more steeply peaked are the images at the focal plane. Therefore, several thin screens that give a shallow, wide light distribution curve would give the best results. Even better results should be obtained at higher cost using a glass plate with the correct radial gradiant neutral density filter deposited on it.

Besides this use of apodizing on the entrance apertures of optical telescopes, a similar technique is used on radio telescopes to reduce side lobes, which tend to pick up stray signals not generated by the source being observed.

By way of disclaimer, I have never used an apodizing screen in my own observing. You now know everything I know about the subject. I hope I have taken some of the mystery out of what can be a confusing subject.

Mark Trueblood
The Irvin Marvin Winer Memorial
Mobile Observatory, Inc.
10912 Broad Green Terrace
Potomac, MD 20854

— I'm always pleased to hear that someone realizes we don't necessarily support the status quo. *As you probably know, Bob has been a driving force in promoting merit award systems at most of the telescope meets in this country, and rumor has it that the hold-outs will be switching to merit awards in the next few years. This is good and fair — and as Bob points out, the nature of telescopes is such that merit awards are better.*

I'll grant that the story on el Observatorio del Roque *needed more hard factual stuff in it — but getting such articles is like pulling hen's teeth! I will redouble my efforts to get more nitty-gritty in such an article before we do any more of them.*

On the use of Dobsonian: although the binocular stand pictured is not a Dobsonian telescope, *I think it qualifies as a Dobsonian* mount. *What distinguishes Dobsonian technology is a reliance on friction, rather than clamp devices, to regulate motion. In azimuth, the binocular stand has a rather conventional Teflon-on-Formica bearing. In altitude, it uses a Teflon washer between wooden side boards, and was friction-regulated, if my memory serves correctly. With light instruments, conventional side bearings do not work properly.*

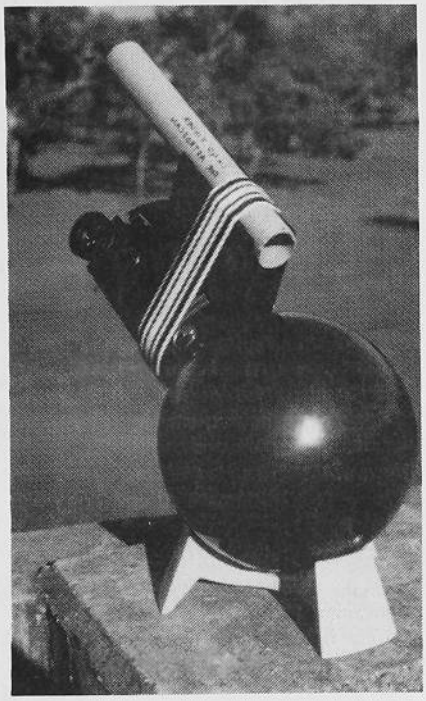
By the way, I hear that your book will soon be out — make sure we get a review copy!

A Simple Finder for Astroscan 2001 Telescopes

Dear Sir / As many other users of the remarkable Astroscan 4" RFT have undoubtedly found, I discovered that the instrument needs a finder because you cannot sight along the tube. This finder has to be bright to match the low power f/4.3 system, but needs no magnification, i.e. a direct sighting tube will do. Edmund does in fact now supply the Astroscan with a metal sighting bracket — this gizmo is aimed at the thousands of users of pre-1982 production models.

However, we solved the problem with a piggybacked cardboard tube some 20cm long and 4cm in diameter, offset from the

cylindrical section of the Astroscan by 8cm — just enough to clear the spherical base. The cardboard core of a roll of household aluminum foil, polyethylene cling wrap or kitchen paper towel is suitable. Dimensions are not critical. The H-profile spacer is made of light plywood and held to the scope with an athlete's elastic sweatband. The whole arrangement maintains alignment and can be rotated freely around the circumference of the telescope tube and is easily removed without tools or modification of the plastic scope body.



It is interesting to compare the specs for a 1x7 finder on a 16x low-power telescope with the standard 6x30 finder on a regular high school-style Newtonian: Note the ratio of 6 in the specifications.

Astroscan Scope: 16x, field 3°; Finder 1x
Newtonian Scope: 100x, field 0.5°; Finder 6x

The coarse cardboard tube is a comparatively accurate narrow-field finder for the RFT. What makes it usable is the fact that the view outside the finder is continuous with the view through it.

Connoisseurs might wish to refine this design by adding a pupil-size diaphragm at the rear of the tube. It is, however, quite easy to place the eye centrally — and the unobstructed "eyepiece" end is more comfortable.

When making your own version of this finder, keep it as light as possible to not upset the balance of the Astroscan design which does not allow for additional external counterweights on the sphere. Access to the two steel internal counterweights requires removal of the optical window which I would not recommend for beginners.

Alfred W. Kruijshoop
P N G Astronomical Society
P.O. Box 33
University Post Office
Papua New Guinea

Pair Design Telescope Mirror

NAU PUBLIC
INFORMATION OFFICE

A Northern Arizona University physics professor and Flagstaff optician have incorporated an innovative optical design in building a new telescope mirror that will offer astromoners increased efficiency and substantial cost savings.

Andrew P. Odell, who teaches physics and astronomy at NAU, and Paul T. Jones, owner and president of Star Instruments Corp., have designed the first fused Pyrex cellular mirror blank for professional telescope use. The pair will introduce their largest prototype, a 48-inch mirror blank, to the scientific community at the American Astronomical Society meeting today through Wednesday in Tucson.

The basic component of a reflecting telescope is the mirror, which gathers light from a distant object and concentrates it into an image at its focus. It is the diameter of the mirror which indicates the size of the telescope. A 48-inch telescope, for example, would contain a 48-inch mirror.

Jones' and Odell's 48-inch mirror blank consists of two circular sheets of glass, five-eighths of an inch thick and 48 inches in diameter. These two pieces are separated by a grid of crisscross glass sections that measure one-quarter of an inch in thickness. The pieces are all fused together by heating the entire assembly in an oven to about 1,200 degrees Fahrenheit.

The approximate concave shape needed for the blank is achieved when the glass slumps over a curved cement mold on which it sits in the oven. The blank will then be ground and polished to its precise curvature and its surface coated with aluminum to produce the final telescope mirror.

While others have experimented with similar mirror designs, Odell said, "No one has ever fused Pyrex on this large a scale."

The internal honeycomb structure of Jones' and Odell's mirror blank offers advantages, in terms of its thermal properties, weight and cost, over conventional mirrors constructed of solid glass.

A mirror of solid Pyrex, a trademark for a brand of oven glassware, is adversely affected by temperature variations, noted Odell. Such a mirror cannot come into equilibrium quickly with nighttime temperatures after having been warmed during the day, he said.

"The large mass of glass," Odell explained, "is a good storer of heat, which can be lost only by slow conduction to the surface. Thus, different parts of the mirror are always at different temperatures and the resulting thermal expansions distort the shape of the mirror, and hence the images."

New Mirror

A telescope mirror, which offers significant advantages in efficiency, cost and weight over other conventional mirrors, has been developed by Northern Arizona University physicist and astronomer Andrew Odell (right) and Flagstaff optician Paul Jones. The designers are pictured with their 48-inch mirror blank. (NAU Photo)

In contrast, the cellular mirror is made of much less glass and, therefore, stores significantly less heat. The honeycomb design also increases the surface area through which heat is lost. As a result, the cellular mirror is a great deal more responsive than a solid mirror to changes in air temperature, according to the designers.

Other solid mirrors have been constructed of zero-expansion glass to combat the problems temperature variations create with the shape of the mirror. Jones and Odell note, however, that the material is very costly. "We wanted to make an inexpensive mirror," said Jones. "By going with the Pyrex and thin cross-sectional inner structure, we found we could end up with the same quality as a solid mirror but at one-tenth the cost." The value of the 48-inch cellular mirror blank will be about $15,000. A solid blank of zero-expansion glass of the same size would cost between $50,000 and $100,000, he said.

A lighter mirror also means a lighter telescope, because the telescope does not have to be as heavy structurally to support the cellular mirror, Jones explained.

Jones has been experimenting with the fused Pyrex cellular design for the past six years through his home-based telescope manufacturing business. He has made several smaller mirrors, which the largest commercial product being a 24-inch mirror. Jones approached the NAU Physics Department about three years ago seeking its involvement in the development of a larger-scale mirror.

Jones and Odell proceeded to build two 40-inch mirror blanks. Jones currently is in the process of grinding and polishing one of the 40-inch blanks, the surface of which he said "should be accurate to within a millionth of an inch."

Odell said they designed the 48-inch mirror blank in hopes it would be placed in a telescope on campus. A 48-inch telescope has the potential of bringing 10 times more objects within reach than the existing 24-inch telescope, said Odell.

Odell and Jones are working to obtain funding to build a 48-inch telescope. Odell also has been evaluating potential locations for such a telescope. Noting that the Flagstaff area is "one of the darkest sites in the United States," Odell said the cinder cones northwest of Flagstaff offer attractive possibilities.

A 48-inch telescope located atop one of the cinder cones, unaffected by light and smoke pollution, would offer even better viewing capabilities, he said.

—The SUN, Flagstaff, Arizona, Sunday, January 13, 1985

Letters

DFM Moves On

Dear Richard / DFM Engineering, Inc. is pleased to announce that we have outgrown our current facility in Boulder, Co., and we have moved to our new location in Longmont. Our new address is:

DFM Engineering, Inc.
1035 Delaware Avenue, Unit D
Longmont, CO 80501
(303) 443-2031.

Dr. Frank M. Melsheimer, President
Kathryn C. Melsheimer, Secretary/Treasurer

On Clark Refractors...

Dear Richard / Clark Refractors: Ray Mitchell was at my place in 1979 and *he* told me that Clark refractors were not any better or any worse than any other makers of that period. Clark just had better press. Had Henry Fitz lived, he might have been as famous as the Clarks. Clark's reputation was made via an o.g. sent to W.R Dawes in England. After that, Clark even further enhanced his reputation with the really large refractors. Soon any 3" to 6" instrument with Clark's name on it was considered "the best." Clark had far worse glass to work with than modern glass. His remedy was local figuring; he had an artist's touch.

The fellow who is making the lens to my 4.5" refractor has told me that a refractor has to be "made pretty bad before it doesn't work good." He has a 5.5" f/10 refractor made out of some of the worst and poorly matched optical glass you have ever seen (he calls it the "Messtar"). Despite this, it performs fairly well on the planets. He made it as an exercise in seeing how good a refractor would be if made from really horrible glass. The result isn't half-bad.

There are, of course, lots of designs and corrections to choose from with any two-element refractor. Some years back, Ray Mitchell put me wise to the B-F correction employed by the Clarks. Howes prefers cemented lenses, but I prefer air-spaced ones. Each has good points and adherents.

Why are refractors better than reflectors, at least generally speaking? Your article in *Deep Sky* #5 lists a lot of them. However, here is one most people forget. Ever hear of a reflecting coronagraph? No, and you won't either. All coronagraphs use refracting elements. Why? No matter how good the reflecting surface, a metallic surface scatters more light than a refracting one. Also refracting surfaces are more apt to be highly polished than the single reflecting surface of the mirror optic. Also, of course, even the best reflectors (except off-axis types) have a central obstruction and that scatters light too.

Check out the performance of a straight-through reflector against a folded refractor. The folded one generally has a lot more scattered light in the field, the result of the additional metallic surfaces involved.

Questar: One of the reasons the Questar works so well (for a 3.5" scope) is the optics are made to extremely high precision. But just as important, there are 21 baffles inside the baffle tube. The result is a telescope whose performance is limited primarily by the 34% central obstruction. My original (1966) Questar had only a 28% obstruction, but when it was converted to a duplex in 1975, they put in a new set of optics that had a larger obstruction. This was done as a compromise to the photographers. As a result, the planetary performance was degraded even with the addition of the enhanced coatings which the 1966 version did not have.

The first diffraction ring is very bright in a Questar — as it is with any scope using a 34% obstruction. It's amazing it works as well as it does. I keep looking for a Questar circa 1965-1966, but they are not easy to find, as there were only about 2,600 made between 1954 and 1966. The MTF reports and computer readouts of the design indicate it's a pretty good system, but there is a noticeable loss of contrast in the lower spatial frequencies, which is to be expected with the central obstruction. A refractor would not show these losses.

Refractors: Someday somebody will start experimenting with fluid lenses again (I'm not referring to Christen's index-matching-oil-between-the-lenses, either). I can't help thinking there's a whole new field out there to explore. Liquid prisms have been used in spectrographs for many years. I see no reason why modern technology can't improve upon the liquid lenses of the last century.

Increasing the focal length can cure some "evils." I recall back in the 1950s, there were two rather long-focus 3" scopes available: the old Goto 3" f/17 and Sans & Streiffe in their mail order catalog had a 3" with a 64" F.L. or better than f/21. I never saw the 3" f/21, but I did see two Goto 3" f/17s, and the color was insignificant. They were great planetary scopes.

After the completion of the 4.5" refractor, I have an 80mm f/11.4 refractor lens that will be going into a brass tube assembly, some parts of which were made by Clark. The 80mm f/11.4 was in a Selsi refractor made

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2.51.1031. Постройка трехзеркального телескопа Каттера. Building a Kutter 3-Mirror Tri-schiefspiegler. Woods A. L. «Telesc. Mak.», 1982, № 16, 10—17 (англ.)

Описано изготовление в любительских условиях 15 и 20 см телескопов из трех наклонных сферических зеркал. К этой системе, впервые рассчитанной Каттером (A. Kutter), внеосевые аберрации зеркал взаимно компенсируются, а зрачок не экранируется. Приведены расчетные параметры оптической системы, допуски на качество поверхностей, на точность углов и взаимных расстояний зеркал (в этом отношении телескоп Каттера предъявляет гораздо более жесткие требования, чем обычные системы). Подробно описаны способы изготовления корпуса телескопа и оправ для зеркал. А. Т.

2.51.1032. Юстировка трехзеркального телескопа Каттера. Collimation for a Kutter Tri-schiefspiegler. Woods A. L. «Telesc. Mak.», 1982, № 16, 18—21 (англ.)

Процедура юстировки достаточно сложна. Сначала добиваются совпадения центров всех зеркал, видимых в окулярное отверстие, затем юстировку уточняют по крестообразной метке, расположенной в центре входного отверстия, причем подробно рассказано, как влияет каждая подвижка на наблюдаемую картину. Окончательная доводка проводится по виду фокальных и внефокальных изображений звезды, ее необходимо проводить только при хорошем качестве изображения. А. Т.

2.51.1026. Передача контраста и разрешающая сила визуальных телескопов. Contrast rendition and resolving power in telescopes used visually. Van Venrooij M. A. M. «Telesc. Mak.», 1982, № 16, 5—9 (англ.)

Популярно изложено понятие частотно-контрастной характеристики (ЧКХ) оптических систем, приведены ЧКХ идеального и неидеального телескопа, рассчитаны ЧКХ и параметры дифракционной картины при центральном экранировании 0; 0,25 и 0,50. Показано, что при визуальных наблюдениях разрешение зависит от типа объекта: если для двойных звезд центральное экранирование слегка повышает разрешение, то для объектов малоконтрастных разрешение, наоборот, падает при экранировании, причем при разном уровне освещенности разрешение тоже будет разным. Библ. 8. А. Т.

in the early 1960s. The guy who had it put it up against some 4" Unitrons at a star party in 1964 and beat them for contrast. I got the lens in 1972 or 1973, but haven't made use of it. Tests show it to be very good. I have heard rumors that Selsi lenses back then were made by Goto, but have been unable to confirm it.

Newtonians: I had a 6" f/12 with a 1" diagonal. It worked excellently. Unfortunately the mirror went bad — but slowly. I did not bother to get it refigured, but traded it back to the guy I bought it from (he had some other bad blanks in the same batch, as time proved). The maker of my 4.5" has an 8" of 69" focus. The mirror was made in 1934 and has not changed one iota. The diagonal is on a single strut and has a 1.25" minor axis.

Have you seen the 5" f/4 refractor offered by Tele-Vue — the four-element one with iris? I saw it in 1981 on daylight objects, but did not get a chance to see it at night. I was favorably impressed with the color correction even at full aperture. Incidentally, don't know if I mentioned it or not, but my new refractor will be on a alt-azimuth mount. I was weaned on alt-azumuth mounts. When I still had the Questar, I used it as an alt-azimuth. I turned on the clock drive twice in 16 years — once to see if it worked and many years later to see if it still worked!

Enclosed is a picture of my 3" Brandon. Managed to find a 4mm original Brandon made by Chester. You will note there are no slow motions on it — you don't need them. Even after thirty years or so, the machining on it has withstood the test of time. The action is so positive you can follow an object with your fingertip. You will also note there are six baffles — more than found in the average commercial 3" refractor. The black crackle finish was considered cheap in the 1950s, but is rather expensive today. Brandon first introduced this scope in 1948. Only three ads were ever published for it, so it's a rarity — far rarer than a Clark or Fitz. I've been offered $700.00 for it, but no thanks. It only weighs 17 lbs., the same as a Questar on a Davis and Sanford tripod does. So long for now.

Roger W. Gordon
637 Jacobsburg Road
Nazareth, PA 18064

— That 3" Brandon refractor of yours sounds like it moves almost as smoothly as Jeff Carmak's 17.5" Dobsonian.

Where-to-Get-It Info

Dear Sir / I'm writing to say that TM is a good magazine and I've read and enjoyed every issue thus far. However, I would like to see an article on how to construct a mirror grinding machine of the Draper or Hindle type — one big enough for large blanks — and some discussion of techniques for working and figuring with sub-diameter tools. I'm also interested in how to cement lenses such as small achromats and eyepiece elements.

I would like to see more reader letters published. I realize that space is limited, but would definitely be agreeable to an increased subscription cost for more details, photos, and resource materials. Another topic of practical value would be on how to design and build a kiln for ribbed blanks. We need to find out more hard data on wiring, materials, and most of all sources for glass plate, firebrick, pyrometers, michrome wire, etc. How to score and cut ⅜" and ½" thick glass plate is another worthy topic. Perhaps you could cover making testing flats such as for windows and diagonals.

I know I'm asking a lot, but I'm sure that the expertise, information, and authors for the articles I'm looking for are already out there in your readership, and will see this letter.

I'll try to do my bit, too. Here's the address of a good source for mail order aircraft quality supplies such as spruce, plywood, chromealloy, tubing, aluminum, fiberglass, graphite, epoxy and fasteners:

Wicks Aircraft Supply
410 Pine Street
Highland, Illinois 62249

Wicks' catalog is almost 200 large pages, a "book" for only $3.00.

Barry W. Wolfe
2507 Nottingham Rd.
Bethleham, PA 18017

P.S. If anybody has been able to confirm the location of the giant warehouse loaded with sheets of 2¼" thick sheet Pyrex, please write me posthaste.

— Articles on cementing and re-cementing achromats and working with subdiameter tools are in the works. Authors for the other topics are still in hiding. . . .

Star Diagonal Fix

Dear Richard / The common prism star diagonal supplied with many popular amateur SCTs can be a source of optical aberration. In over half the new telescopes I've tested, the prism is cocked or tilted, which degrades image sharpness. Fortunately this is easy to fix. Using a jeweler's screwdriver, loosen one of the small set screws in the side of the star diagonal body. An internal spring should then push the prism back into its correct position. Then retighten the set screw. I strongly urge all users of telescopes with star diagonals to make this simple effort at improving image quality, especially purchasers of new telescopes.

Dr. Jack B. Marling
Lumicon
2111 Research Drive
Livermore, CA 94550

Seeing Double

Dear Richard / I just want to thank you for the coverage of my project and the time you've taken to really understand it. I'm sensitive that the advantages of binocular vision be stated accurately. For the neophyte to hear that the images are "twice as bright" is misleading. But the advantages for experienced deep-sky observers are very real; your coverage in TM#23 stated the case very well. I hope TMs will experiment with large binoculars for a variety of applications. With today's cheap mirrors, it's become a practical alternative for better visual astronomy. Large binocs will remain specialized instruments, of course, but those willing to pay for the additional optics will discover they fill their own niche as the "Schmidt camera" of visual astronomy.

Lee Cain
16206 Grassy Creek
Houston, TX 77082

STATEMENT OF OWNERSHIP, MANAGEMENT, AND CIRCULATION

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Notes on

I'm driving south from Wisconsin on the last day of summer with my telescope in the van behind me, new camera loaded with film, trusty computer with a fresh set of alkaline AA cells, a new modem for Bob Cox, and some goodies to sell at the swap table: yes, it's AstroFest time again. I like the late summer, when the grasses are that somewhat tired shade of green fading into golds and browns, but the landscape is still rich and full and lush. It's the Chicagoland rush-hour traffic on 294, the crazy late Friday afternoon drivers, the toll booths that seem out of place. Finally south on I-57 the land is flat, and I'm rolling past corn fields being harvested, the air abuzz with insects even from the highway.

I arrive early — an hour before sunset — pull into a gap between a car and a pickup truck, each with telescope set behind it. Along the row of cars and across Camp Shawanasee's athletic field are a scattering of other telescopes — a good dozen already. Although wispy clouds in the west do not bode well for a clear night, they don't suggest imminent storms either. Among them I recognize several telescopes from previous years.

It feels good to climb down and stretch after the drive. Walking over to the camp office, I know within minutes that my sinuses aren't going to like it here any better this year than they have in past years.

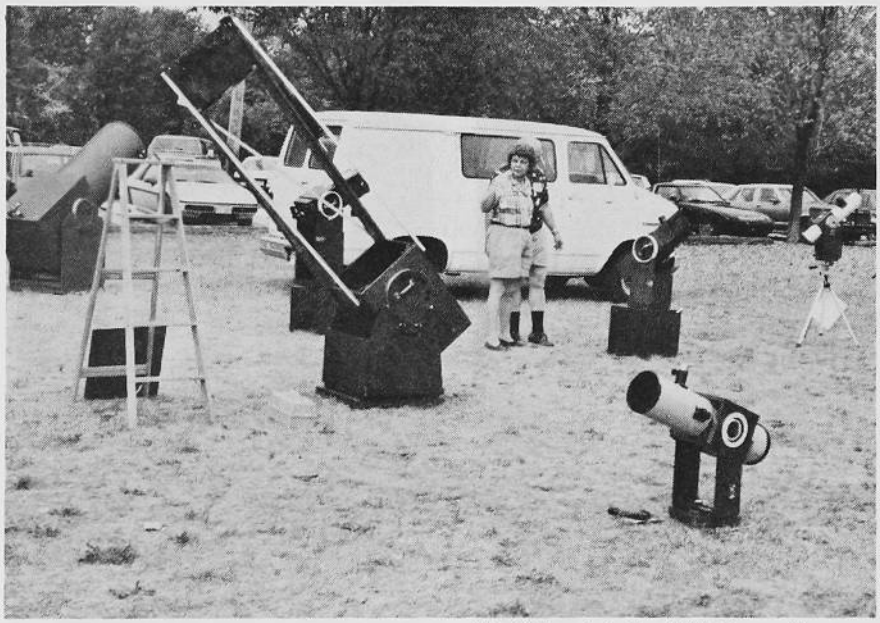
As the Sun drops into the trees, more cars and trucks and campers have arrived. The air feels cool and dry. For once — things too seldom work out so nicely — I've arrived with ample time to set up while it's still light, and still have time to look at the other telescopes before dark. I register, deliver the box of AstroMedia doorprizes and freebee Deep Sky Object cards (more than enough for every registrant!), then head back to the van to unload the telescope.

After four years of use, the yellow paint on the tube of the 20-incher has become rather badly banged up, and I never have gotten around to painting the rocker box. Assembling the telescope is now well-rehearsed ritual — set out the base, bolt the side boards on, drag the tube out and set it in the rocker, strain to lift the mirror box into place, bolt on the upper end, and finally attach the finder. I give it a solid push and it responds smoothly.

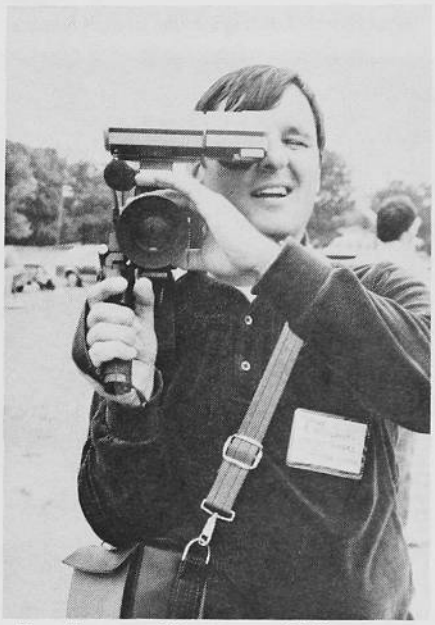
Suddenly I hear a familiar voice — Bob Cox — and we're immersed in the articles he's working on, the articles I'm working on, and the details of Bob's new modem. TM, you see, is entering the age of electronic publishing by linking Bob's Atari to the Vector Graphic computers at AstroMedia. Soon afterward, I find myself talking to Tom Burns, one of the Ohio contingent, examining the little crowd of brown-stained Dobsonians around him. As Tom says, "It's a fact of nature that each can of brown stain runs out in the middle of the job, so you have to buy a new can of brown stain to finish it." The biggest of the Ohio telescopes is the 16″ Boppian, but the 4″ f/6 Schmidt Newtonian, the Cassegrain, and the little RFT with red running lights also deserve a closer look.

For a while it looks as if the weather will hold, but as darkness falls, clouds press in from the west, dimming the first stars. Drifting back to my own scope, I plug in a 32mm Koenig to see Jupiter, and discover that the seeing is pretty bad. Young Tim Ahearn and his father stop by, and soon they get to see Jupiter, too. Mars is easy to spot, as is Antares, but I can't make out Saturn

AstroFest 1984



The Ohioans' circle of little brown telescopes, and the 16" Boppian reflector.



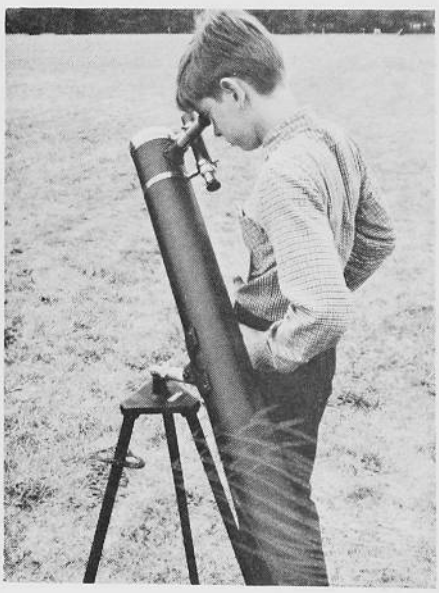
Tim Ahearn and his 28-year-old Skyscope.

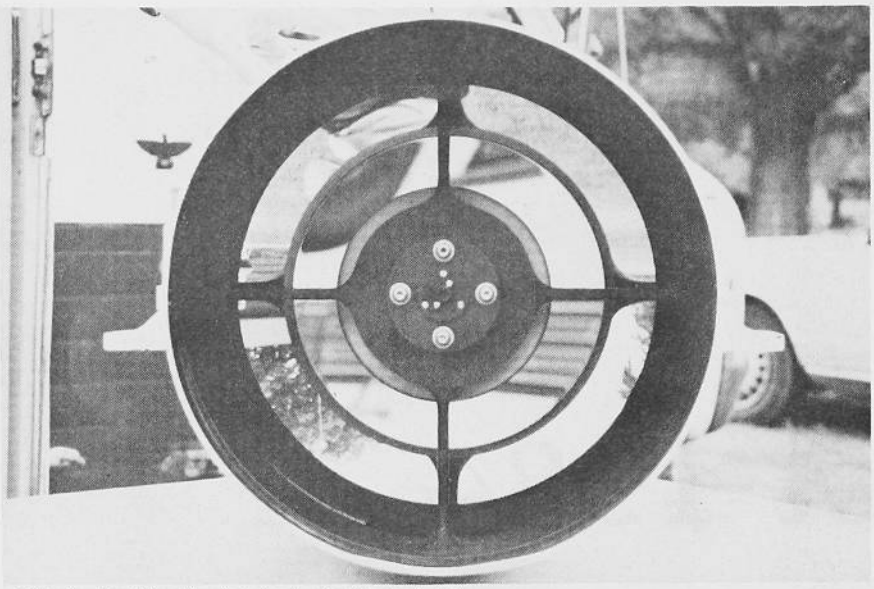
down in the murk. Tim gets his first look at a not-very-impressive Lagoon Nebula, rather washed out in the still-bright sky through partial cloud cover.

While we're messing around trying to find Saturn, another amateur (whose name I never got) joins us. He says he'd like to try his new eyepiece on my telescope. It's a 38mm surplus Erfle from the American Science Center. I'm slightly dubious (at f/4.9, the exit pupil will be somewhat too large), but say, "Sure, let's try it." The eyepiece he lifts out of a paper bag is enormous, and weighs about half a ton. A moment later, though, I'm oooing and ahhing at the extraordinarily wide field and crisp images. The oversize exit pupil, while wasteful of light, is "comfortable" to the eye, and allows me to observe without removing my glasses. It is much better in this respect than my Koenig — for which I traded a 32mm Erfle several years ago, specifically because of the Koenig's better eye relief.

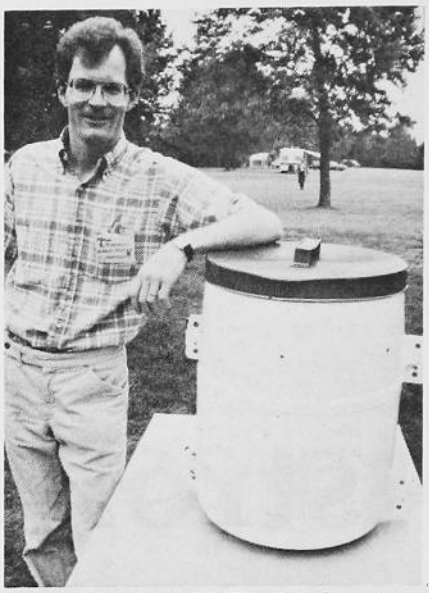
We're all so enthusiastic that the 38mm Erfle spends a good part of the next two hours on my 20". Tom Burns brings over *his* 32mm Koenig equipped with a 2" Lumicon UHC filter, so, despite steadily worsening clouds, we manage moderately good views of M-8, M-20, and, of course, the Veil Nebula. The filter is very impressive.

Since I'm here reporting, after a while I leave the 20" with several enthusiastic observers and head off to try some other telescopes. While waiting to look at something through Tom Burns's Boppian, we begin talking to a couple who soon introduce themselves as Murray and Gloria Foster. They are

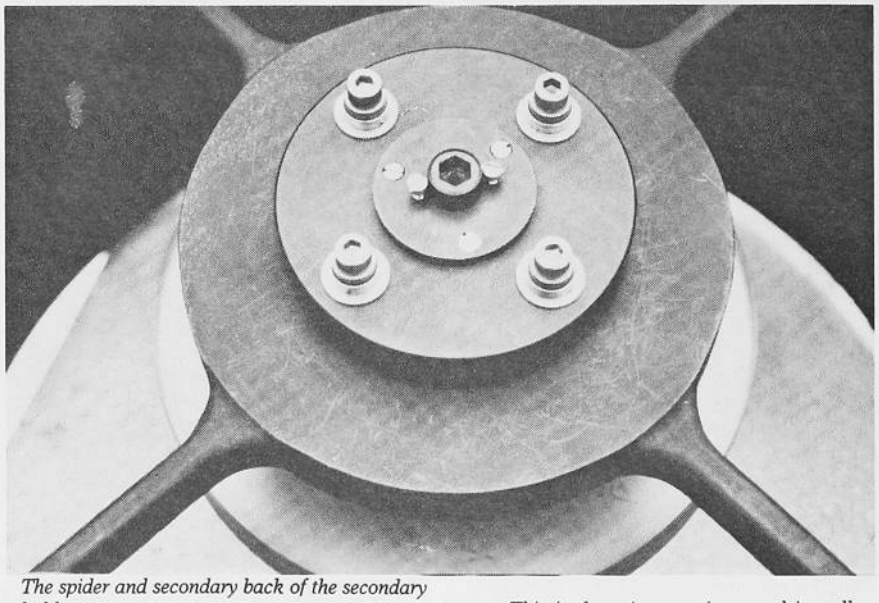




What's what? Looking into the front of Foster's 16".

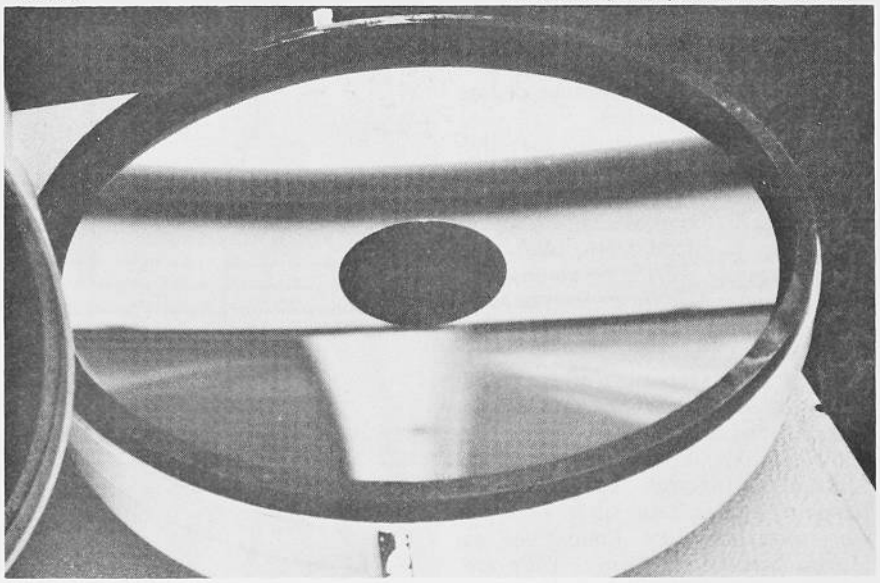


Murray Foster and R2D2, the telescope.



The spider and secondary back of the secondary holder.

Me reflected in the secondary.



This is the primary mirror and its cell.

quite new to amateur astronomy, but Murray has stumbled across a unique optical system — a 16″ missile tracking telescope. It arrived, via airfreight, just a few days before.

They have named the lens R2D2. Would we like to see it?

Tom and I leap at the chance, so minutes later, find ourselves looking at a Cassegrain optical system about the size of a 20-gallon steel drum. It's about 18″ in diameter and perhaps 24″ tall, and weighs in at 85 pounds. The primary is 16″ in diameter with a radius of roughly 32″; the secondary is roughly 7″ in diameter and spaced 12″ from the primary. Construction is first-class throughout. The effective focal length is a mystery. The surplus dealer claims the system is f/4, and was made by Hughes. At any rate, Murray would

welcome hearing from any TM reader who can help him in finding the specs and/or original spacings for the system. Write to: Murray Foster, III, M.I.U. Faculty Mail, Fairfield, IA 52556.

Later, although the sky has gotten quite murky, we traipse over to the little Ohio RFT to see the California Nebula through Tom's narrow band H-beta filter. It certainly makes the sky dark, and eliminates all but a few stars in the field of view. I think I see an arc of nebulosity, one of brighter wisps, in the object, but it is pretty marginal. I first saw this object from the Mojave Desert several years ago using an Astroscan and a Henzl 500 filter.

The evening concludes when clouds finally became too thick to see anything through — besides the effects of a long day catch up with me. I roll out my foam and sleeping bag on the floor of the van and soon fall asleep.

Morning comes all too soon — with dawn, in fact. My nose and sinuses have gone crazy during the night, there in the middle of polleniferous farm country. A decongestant helps considerably — and also helps put me back to sleep. It's sometime around 8 before I totter over to the dining hall looking for donuts and coffee. Especially coffee.

To my amazement the swap-meet has already begun. All sorts of biggish mirror blanks, a huge assortment of Teflon scrap, and lots of camera bits and pieces are arrayed on tailgates and tables. Bob Cox, bright and chipper, is offering a mounted set of 10″ SCT optics at a good price, and is busily talking to Dick Wessling about an article for TM. I make some sort of excuse for not being sociable ("I feel like s---") and go in. Several jumbo cups later my disposition improves.

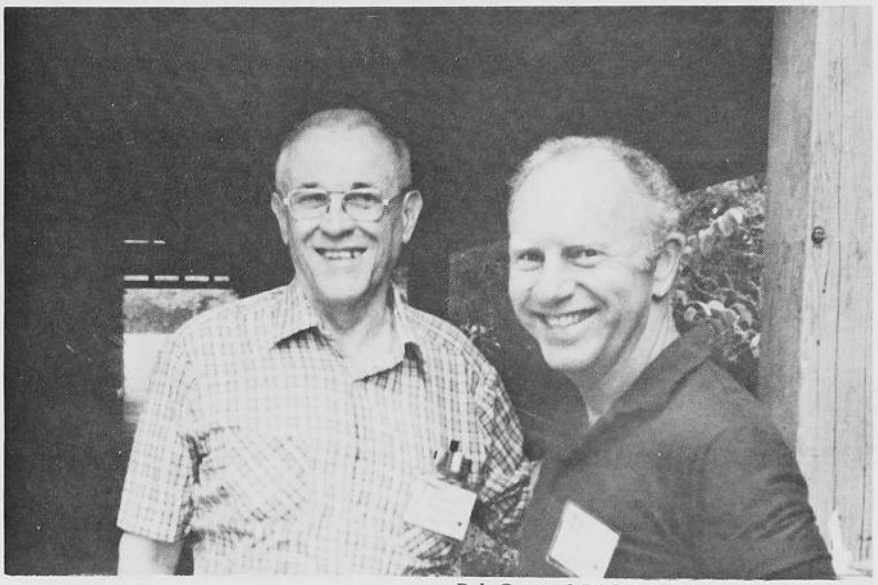
But there's no time to waste! Back to the van. Grab the big box. Lug it back to the swapmeet. Find a table. Spread out the stuff. During the whole time I've been writing *Build Your Own Telescope* I've been buying telescope stuff; now I hope to unload some of the extra goodies I've acquired.

The Aero Ektar and finder telescope sell in minutes. When things calm down, I have time to look over goodies arrayed on other benches — and purchase two elderly star atlases.

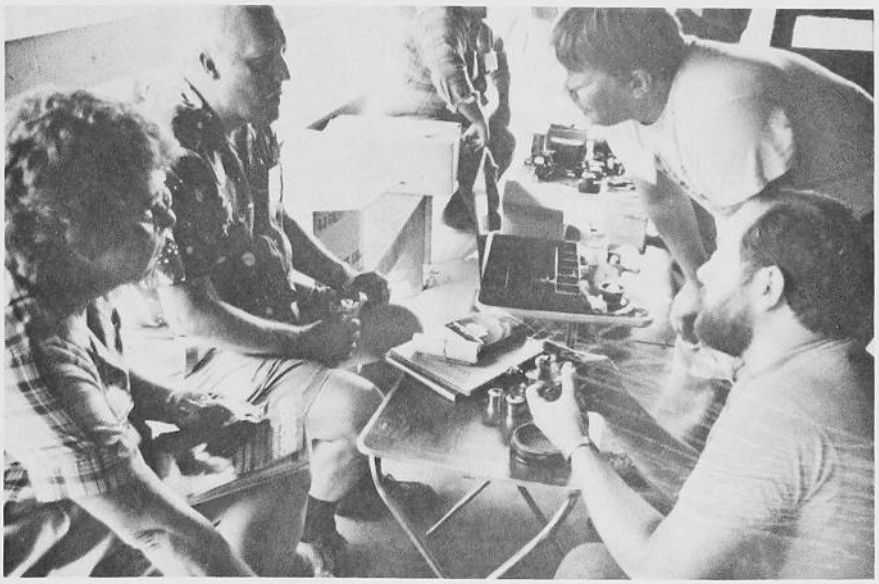
Since day had not dawned clear, nobody was really surprised when word came that the telescope display and judging would be held between 10 and 12 instead of the afternoon — rain was forecast. I left the swap area, picked up my camera and notebook for a perusal of the field.

Gil Machin is just a few scopes down from mine. He sold his 18″ Dobsonian last year and had a new telescope: a

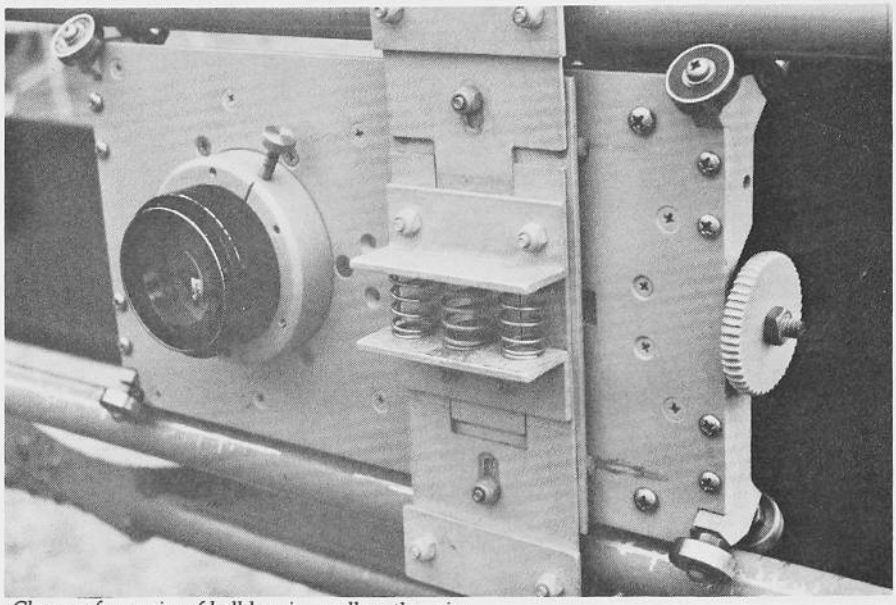
All this good stuff is for sale?



Bob Cox and Dick Wessling — early birds.



"Let's put in a proper eyepiece for the picture."

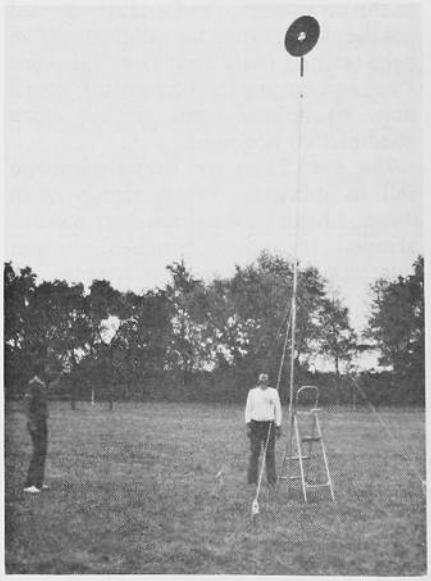


Closeup: four pairs of ball bearings roll on the pipe.

massive fork-mounted 16.38″ f/5.6 Newtonian on a trailer. It looked easy to set up and use — for drive-to-the-site style observing. The telescope tube was built up from eight lengths of tubing with flat metal panels riveted to them. I was impressed with the heavy cross-section of the fork, but the telescope won an award for the focuser. Like the Crayford eyepiece, the focuser rolls on two of the tubes with small diameter ball bearings, but unlike the Crayford, the whole focuser body and the diagonal move. Gil says it stays in alignment quite well.

Tom Martinez showed me a gizmo for polar aligning for an equatorial platform. Since the polar axis is normal to the surface of the inclined plate of the tracker, he had constructed a right-angle holder for a right-angle finder. The finder simply rests on vee-blocks on the holder, and the holder itself is clamped to the inclined plane. Tom's is still one of the most sophisticated equatorial platforms I've seen. Incidentally, he's got a cute idea for protecting the diagonal mirror of the telescope. It seems that a cut-off plastic cola bottle slips over the 4″ diagonal holder of his scope. If you don't have a diagonal of that size, too bad. But bottles are readily available, in any case, and come in lots of sizes. . . .

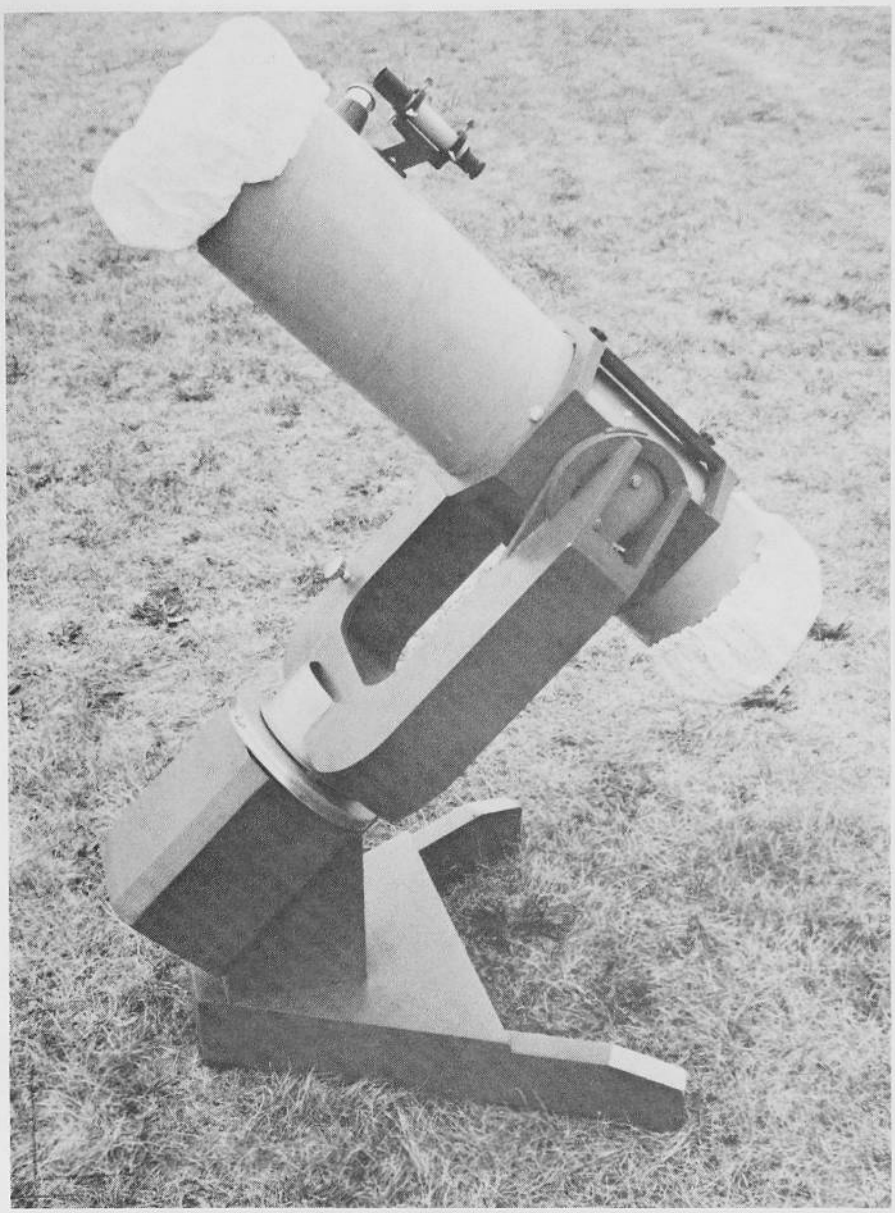
On the far side of the field was something that looked like a TV antenna with a lollipop on top — Chuck Thomspon's latest experiment. He had glued three glass disks into a piece of aluminum and then ground and polished the three as a single lens of 45-foot 10-inch focal length. The triple lens is attached to the spring from an arm exerciser and mounted atop the 23-foot pole; by pulling on a rope, the aluminum plate will bend over. The



idea is then to catch an image with a hand-held eyepiece, somewhat as the 17th Century astronomer Huygens had done with his pole-mounted telescope. Since there is no provision for aligning the lens, nor any way to remain at the correct distance from it, Chuck's scope is mostly in the spirit of fun. He said it didn't give good images, but it got lots of attention.

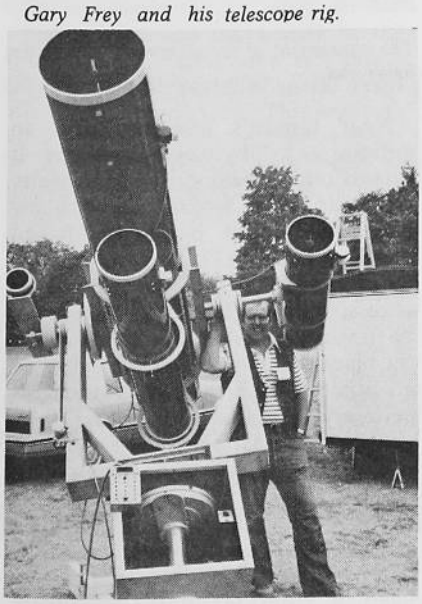
Across the field from Thompson was Gary Frey's massive fork-mounted multiple telescope. It looked a bit like an anti-aircraft battery with its four parallel tubes pointing skyward. The main scope is a 14.25″ f/6, and there are two 8″ scopes — one for guiding and one for photography — plus another 4.25″ for photography. Frey had put something like 1000 hours into building the instrument, and plans to mount it in a permanent observatory. He's got electric focusing on two of the instruments — "Works great for planetary," he says — and a 32″ tangent arm for declination slow motion. The RA drive is a single strand of 0.030" wire pulled by a lead screw. Frey plans to beef it up with more strands of wire since the scope has a rather "boing-ey" feel in RA.

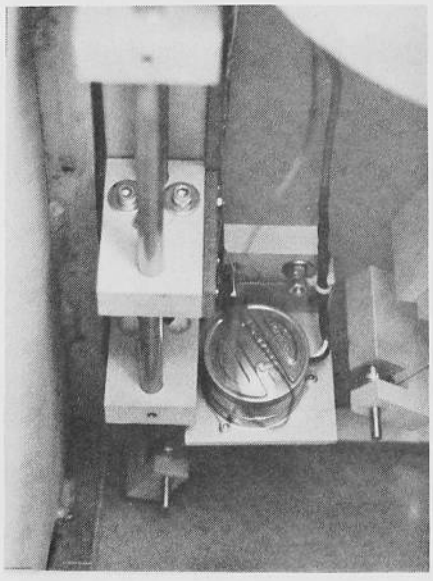
Among the bigger and showier instruments was a sweet little 6″ f/6 fork-mounted Newtonian made by Jeff Inman. Last year I took some pictures showing this telescope's pipe-clamp metal and wood RA drive gear. Using plywood and plastic pipe, Inman has fashioned a solid and workable instrument. His wife Debbie comments, "It's the grinding of the mirror he spent so much time on." But that's always the case in telescope making, isn't it?



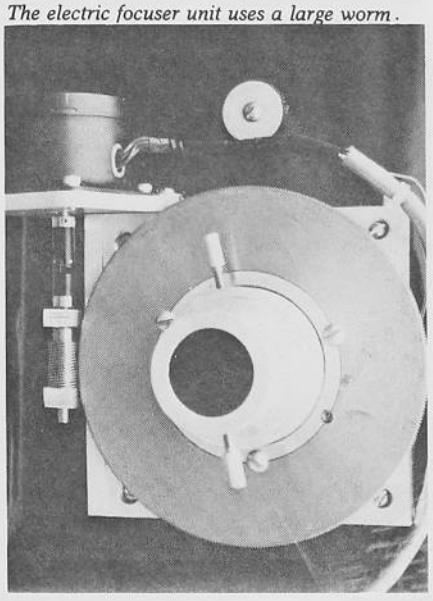
Jeff Inman's tan and green 6″ f/6 Newtonian is compact and convenient.

Gary Frey and his telescope rig.



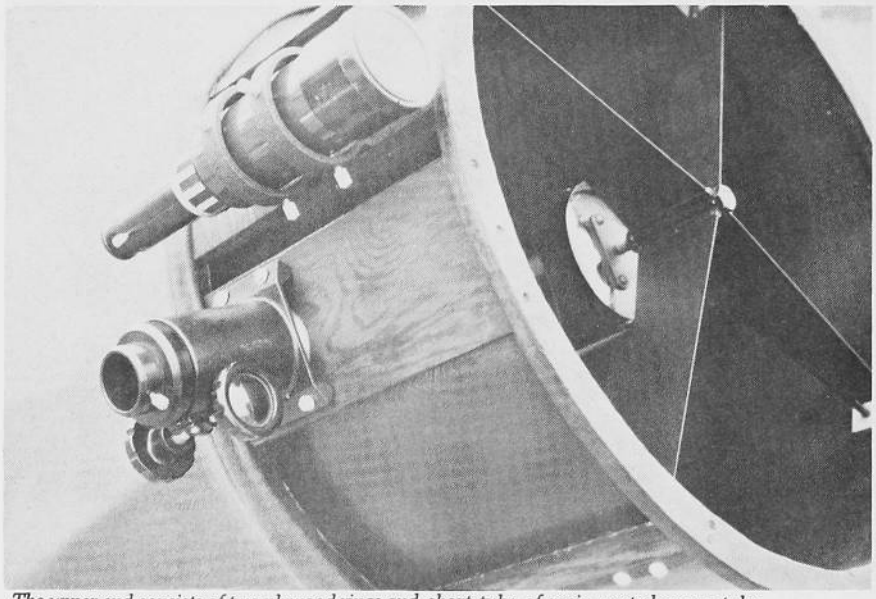


The electric focuser unit uses a large worm.

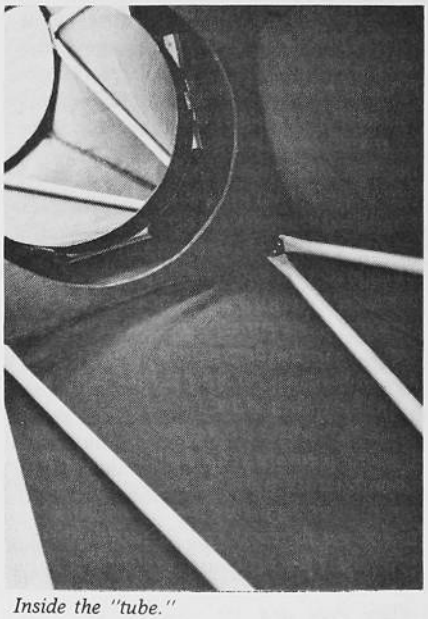


Doug Nelle and his lightweight open-tube Dobsonian with cloth tube installed.

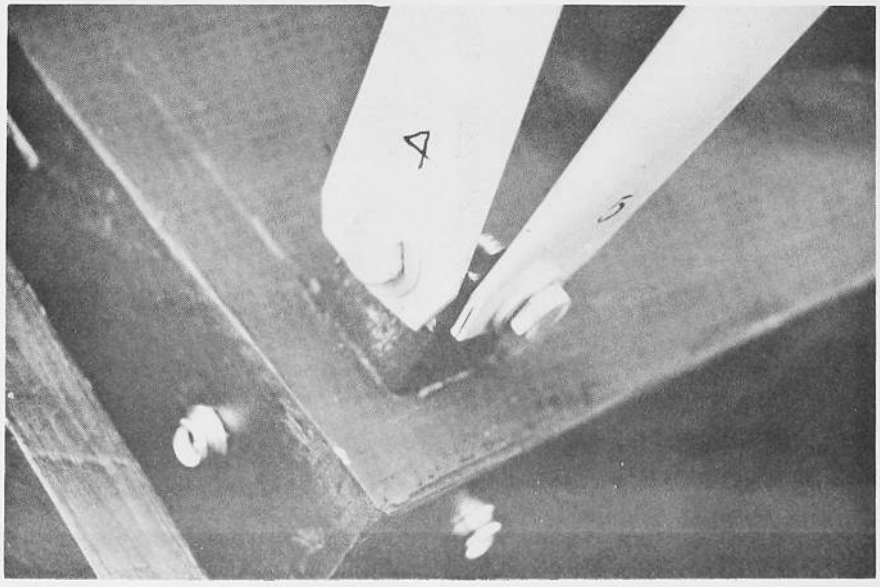
Aluminum rods at the upper end.



The upper end consists of two plywood rings and short tube of resin-coated paper tube.



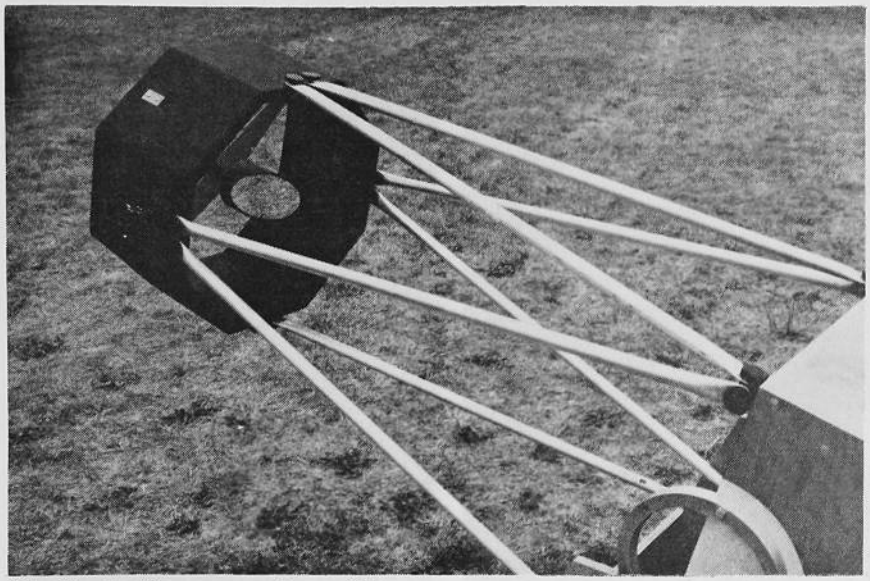
Inside the "tube."



The attachment of the aluminum rods to the lower end.

Near Inman's telescope was an antique — a 28-year-old Skyscope. It turned out to belong to Tim Ahearn, who had been looking through my scope the night before, and had originally been his Dad's. I wonder how many of us began our observing career with something like it? It appeared to be in very good shape — right down to the black paper on the tube. I didn't get a chance to look through it, though I certainly would have liked to.

This year at AstroFest there were two of the lightweight 17.5″ Dobsonians pioneered by Eric Holberg. One had been built by Doug Nelle from light plywood and aluminum tubing; the other belonged to Roger Tanner, and used a fiberglas-foam composite



The fiberglass-foam upper octogon of Roger Tanner's lightweight Dobsonian.

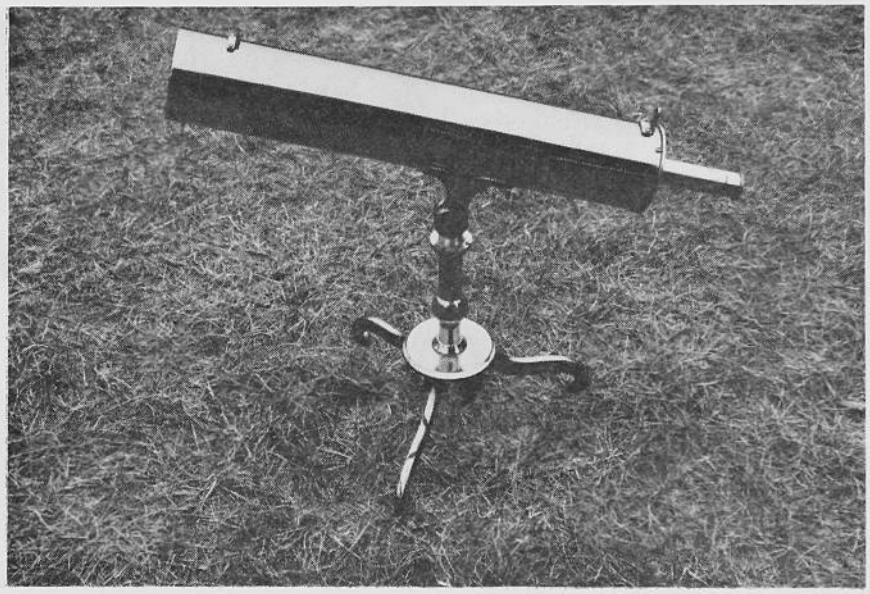
Don Daniels and his replica of the Adler's Short.

octagonal upper end. The trick is to keep the weight of the front end of the telescope at a minimum so the balance point is only a short distance ahead of the mirror. This means that the lower tube is short, so the rocker box can be low so the eyepiece will always be convenient.

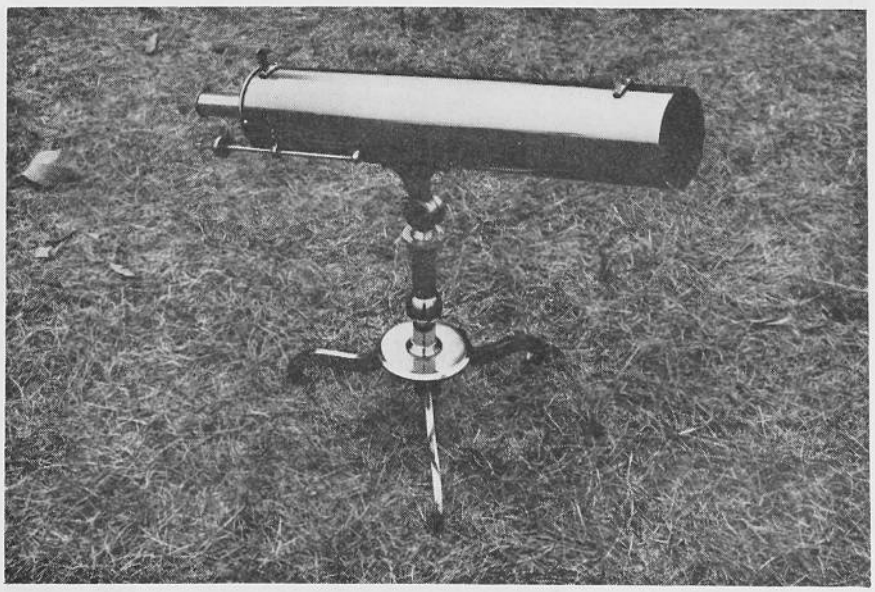
I had more time to inspect Nelle's. The upper end is made from two 1″ wide by ¾″ thick plywood rings stiffening a fibreglass-resin-reinforced paper tube. The open framework tube is made of eight ⅞″ by 0.047″ wall aluminum tube. Doug crushed the tubing between pieces of plywood with a C-clamp; the tubes are attached at both lower and upper ends to compact brackets made of angle iron with ¼″ hex head bolts. At the lower end, each bracket also reinforces the corner of the tube box. For repeatability, individual tubes are numbered.

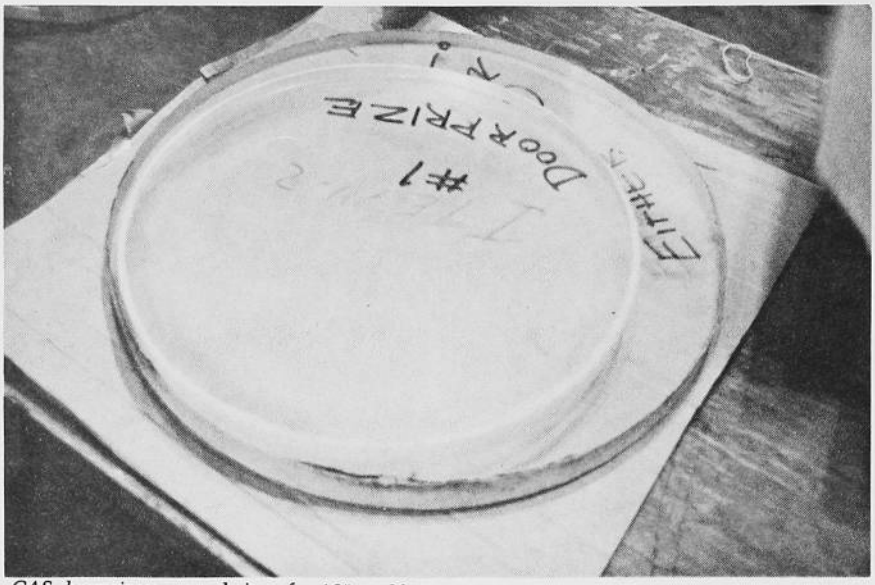
Nelle covers the framework of the open tube with dark blue knit fabric which is held in place by metal snaps from the hardware store. This seems to work very well, since the tube need not be completely covered. Says Nelle, "It really helps with light. My site is 10 or 12 miles as the crow flies out of Ann Arbor."

'Way down at the parking lot end of the field was a telescope that looked out of place on the dry grass of the athletic field. Made by Don Daniels, it was a beautiful brass replica of a classic refractor, a copy of an instrument at the Adler Planetarium. The curators allowed him to examine the original there, and even to trace patterns. The tailpiece of the replica reads: "James Short — London 1752." Daniels used #85 cast brass for the fittings and rolled brass for the tube. "The only thing I



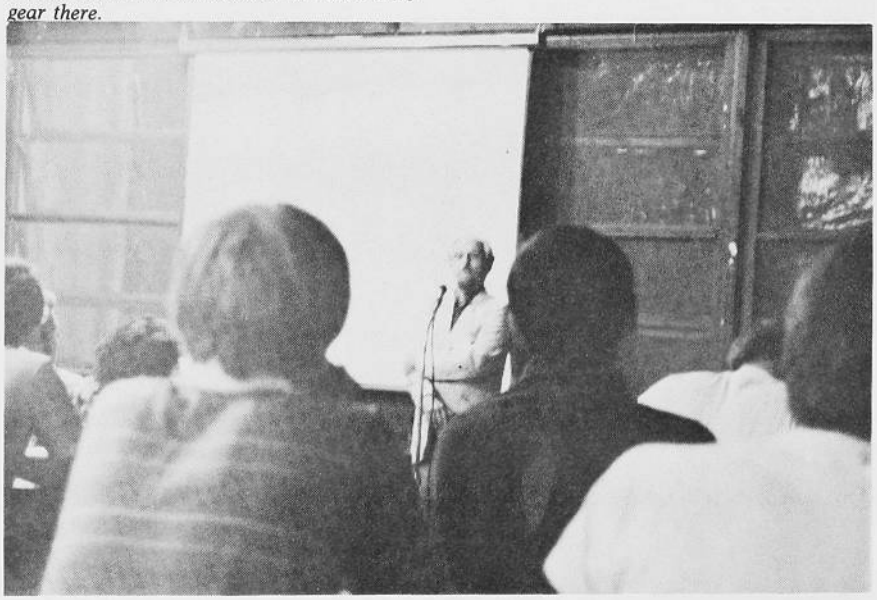
Daniels' two-tone brass replica.

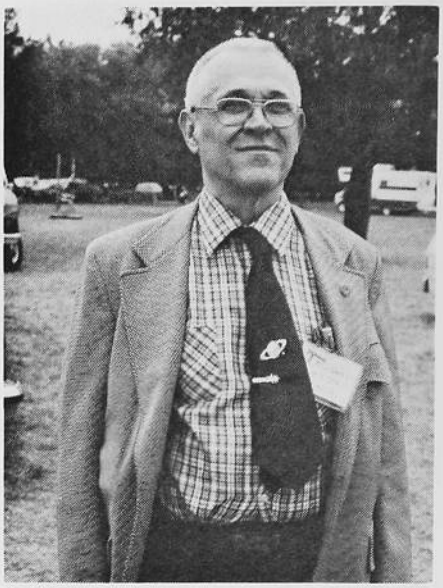




CAS doorprizes: your choice of a 16" or 20" blank.

No slouches here at AstroFest! That's some drive gear there.





couldn't duplicate was he [Short] used hex heads for all the screws." The objective is a modern one. Said Daniels, "I really don't use it — it sits on the stereo cabinet in my front room."

I have still not seen all of the telescopes when the rain begins. First a few drops, then a sprinkle that keeps up. Some exhibitors run for the plastic sheeting; others decide to pack it in and take their scopes down. I take down the 20-inch and put it in the van, but wrap the mount in plastic. If I load both in the van, there'll be no place for me!

Intermittent drizzle turns into a light rain about the time my astrophotography workshop begins, so I have a big audience. I began by showing the slides taken at Riverside on Kodak's P800/1600 slide film pushed to 3200 ISO. These had come out quite well — the scene lit by the dim glow of red flashlights — arched over by the trails of stars. The trial startrail exposures taken with a 50mm lens at f/2.8 show the Milky Way fully exposed in 20 seconds, and overexposed in 60 seconds.

Raw film speed! They're rather grainy, of course. After the slide show, we have a half an hour for discussion — fairly lively considering how tired we are — before the hall is cleared for dinner.

This year's after-dinner speaker is Charles Capen. His talk spans the history of martian nomenclature, high-altitude ballooning, and photographing Mars with color filters. Some of his Mars photographs are really knockouts; I had never realized just how good the *very best* ground-based pictures are. He concludes with the intriguing suggestion that during the next two apparitions of Mars we should look for several of the biggest craters on Mars, now that we

Gil Machin

Sittin' out in the drizzle. . .

know where to look for them.

I didn't really want to see *War of the Worlds*, so I end up in the kitchen talking to Burton Stevens, president of the Chicago Astronomical Society, and members of the AstroFest committee. These people deserve a lot of credit for running a well-organized and very pleasant meeting. At some point, though, I remember that my swap-meet stuff is still sitting outside on the bench, so excuse myself and go off to collect it. While I am fussing around trying to get it all packed back into a soggy cardboard box which now seems much too small, Jan Madenberg, another CAS stalwart, comes by to invite me to attend the CAS's Apple River Canyon. I decline, explaining that writing this article and finishing another issue of TM, not to mention the ongoing pressure of ASTRONOMY, precluded it this year — and so we end up talking about crazy jobs that never seem to end.

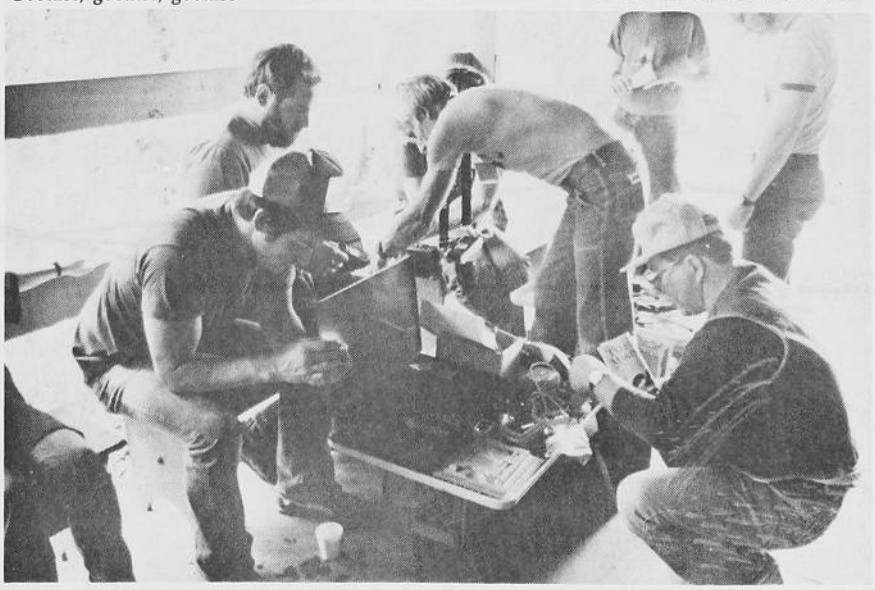
When the movie ends, Bob Cox and I spend a while planning how we'll use TM's new modem, then shake hands and he leaves for the bunkhouse. Bob is a morning person — he is planning to be on the road at dawn the next morning for the long drive back to St. Louis — so we won't meet at breakfast. I walk to the van through the rain, squeeze into the sleeping bag nestled between a wheel well and the bulky tube of the 20-incher, and fall asleep only to be wakened by a downpour sometime in the wee hours — wind-driven rain makes quite a din on a metal van body.

In the morning I find the 20"'s mount still dry under its plastic, so I knock it down, bundle it in beside the tube, have morning coffee and donuts, say my goodbyes, and head for home.

— *Richard Berry*

Goodies, goodies, goodies.

From the CAS: Bert and Jan.



Eyepieces

Introduction

Christiaan Huygens, father of the wave theory of light, learned of Snell's law of refraction and derived from it an optical aberration theory. His eyepiece, dated 1703, is probably the first professionally-designed lens. The Ramsden followed in 1743, the Kellner in 1849. With the invention of the Erfle in 1921, it must have seemed that eyepiece evolution had reached its peak. Today we know that is not true.

We must appreciate what a chore lens design was before computers became widely available in the 1960s. As computers and lens design programs improved, it became possible for almost anyone — professional and amateur alike — to explore complex ideas that previously had been ignored. What we *have* verified with computers is that so long as we constrain an eyepiece to be small and simple, the theoretical limits had indeed been reached by 1921. Once we allow ourselves to spread out, however, some truly fine imaging systems become possible. But it is probably no longer proper to speak of them simply as eyepieces.

Magnifiers and Eyepieces

An eyepiece is always a magnifier, but a magnifier is not always an eyepiece. An eyepiece is, by definition, an attachment to some other instrument that contains an aperture stop. The exit pupil of that instrument is the entrance pupil for the eyepiece and the image of that exit pupil becomes the exit pupil of the eyepiece. The observer positions his eye in the exit pupil of the eyepiece. Imperfect alignment of the eye, as well as a defective image of the aperture stop, result in vignetting.

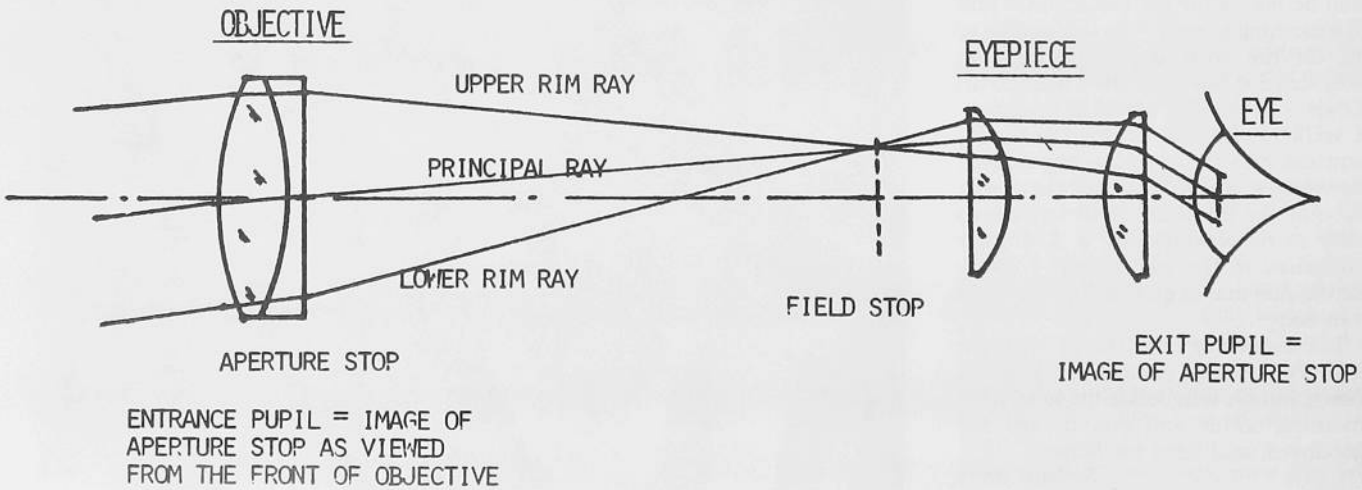
A magnifier is a stand-alone instrument; the eye becomes the aperture stop of this instrument. In most magnifiers, the eye's precise location does not produce vignetting, although optimum image quality is obtained for just one eye position. Many eyepieces make dandy magnifiers, but the reverse is not always true.

The term "positive eyepiece" is applied to those that have an external object focal plane. A "negative eyepiece" is one that has a virtual object focal plane. We can, therefore, use a positive eyepiece as a magnifier, but not a negative eyepiece. The Huygenian and many of the most recent designs are "negative eyepieces."

Magnification

Casually speaking, magnification is a measure of how much bigger the object looks *with* rather than *without* the telescope. If we want to talk about aberration, we need to be more specific. We won't talk about imaging three-dimensional objects since astronomical objects, for all practical purposes, are so far away that considering them as planes gives fine results.

Telescopes are termed "afocal optical systems," which means their focal planes lie at infinity and their front and rear focal lengths are infinite. (Your eye forms the real image; the telescope projects a collimated beam.) It is



appropriate to study such a system with angles, because both the object and its images are substantially at infinity. Strictly speaking, a telescope is not a telescope when we defocus its eyepiece, as, for example, we might when viewing the Sun, but the rules turn out to be almost the same.

Angular magnification of a telescope is given by the rule:

$$M = -F/f$$

where F = the equivalent focal length (EFL) of the objective, including relay optics and anything else preceding the focal plane; and f is the EFL of the eyepiece subsystem. A negative magnification means the image is inverted.

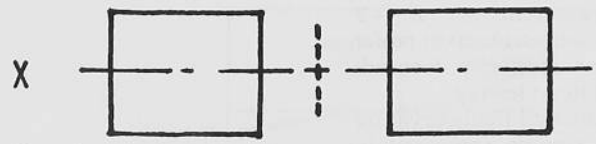
For perfect imaging, the angular image must be a magnified version of the angular object, but we must deal, instead, with the *tangents* of real central rays. Thus the usual rule that apparent field of view equals telescope magnification times real field of view is incorrect. For a distortionless image, the tangent of the apparent semi-field equals the magnification of the telescope times the tangent of the real telescope field semi-angle.

But here we run into practical problems. Because most eyepieces have a lot of positive (or pincushion) distortion, their apparent fields seem 10% to 30% greater than predicted by Gaussian theory. Designers do their best to reduce this aberration, but wide-angle buffs seem to tolerate it well. Advertisers sometimes behave as though this defect were an asset.

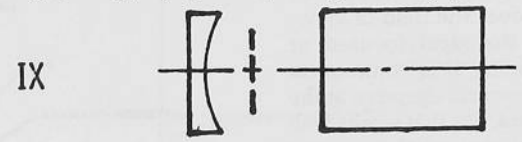
When we observe in very faint light, our eyes involuntarily shift focus to a distance about a meter away from us. Those of us who wear glasses may remove them and refocus the telescope, changing the eyepiece focus by ten diopters or more for some people. If the eyepiece were simply a magnifier, then the magnification would change drastically — but with a telescope we find little change at all. In fact, if the objective were infinitely far away, we'd have a telecentric (infinite distance to the pupil) pupil and magnification would be unaffected by defocusing the eyepiece. We can, if we wish, create this scientifically favorable condition by adding a field lens to the telescope, or by devising a special, internally focusing eyepiece that maintains the proper conditions.

Diopters and Focusing

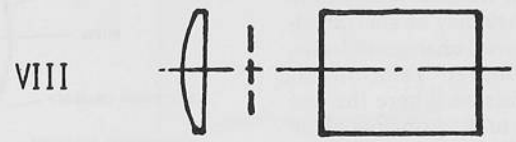
The diopter is an opthalmic measure of lens power measured in reciprocal meters. A 500mm focal length lens is a 2 diopter lens; a 2000mm SCT lens is an 0.5 diopter lens, and so forth. The markings on a modern military eyepiece are likely to run from −6 to +2 diopters. It's not uncommon to find



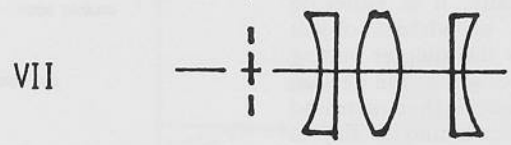
Erecting (Relay) Eyepieces, Integrated Eyepieces



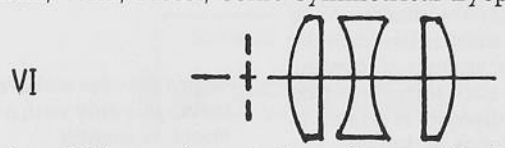
Scidmore, Nagler, Cooke, Klein



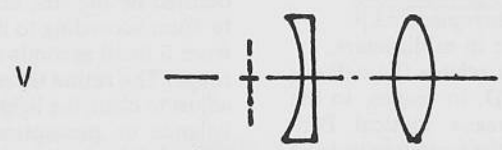
Shoemaker, Uetake



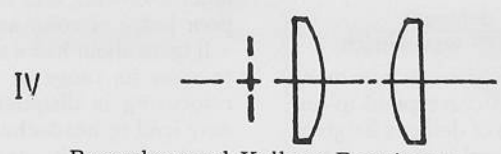
Erfle, Wild, Plossl, Some Symmetrical Eyepieces



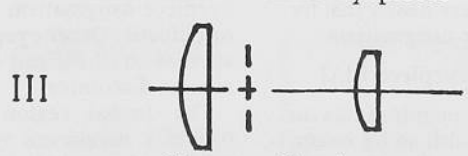
Monocentric, Orthoscopic, and Some Symmetrical Eyepieces



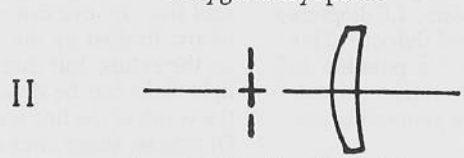
Asymmetric



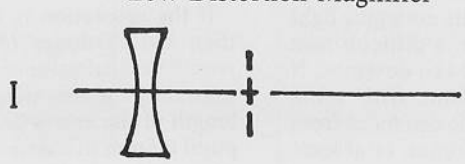
Ramsden and Kellner Eyepieces



Huygens Eyepiece



Low Distortion Magnifier



Galilean, Opera Glass, Catadioptric Finder

fixed-focus equipment set at −2 diopters. Rarely does an observer prefer the zero diopter (perfectly focused) setting for extended viewing.

The astigmatism and field curvature of an eyepiece can be expressed in diopters. These aberrations behave like selective power over the field of view, departing from the ideal focused or collimated condition. It is common to analyze an astronomical eyepiece at the infinity focus, a practice that works well with conventional conservative designs, but it can lead to trouble with exotic designs because they may be aberration-sensitive to even small changes of focus.

The exact diopter relation to defocusing depends on where the eye is located relative to the principal plane of the eyepiece. Rather than solve the problem analytically, it is easier to produce a real or virtual object corresponding to the diopter setting desired, with its origin at the desired exit pupil. This object is then raytraced through the eyepiece to find the shift in the image plane relative to its infinity focus. However, it is not uncommon to find approximate formulas based on the assumption that the amount of focusing will be small. One such formula is that the adjustment in dipoters is related to the amount of defocus as follows:

$$\text{Diopters} = \frac{1000 \times \text{defocus}}{(\text{eyepiece f.l.})^2}$$

All dimensions are in millimeters.

Another formula relates the defocus aberration, or OPD, in waves, to the defocus. OPD means Optical Path Difference, and is the usual measure of wave aberration.

$$\text{OPD} = \frac{\text{defocus}}{8 \times (\text{f\#})^2 \text{ wavelength}}$$

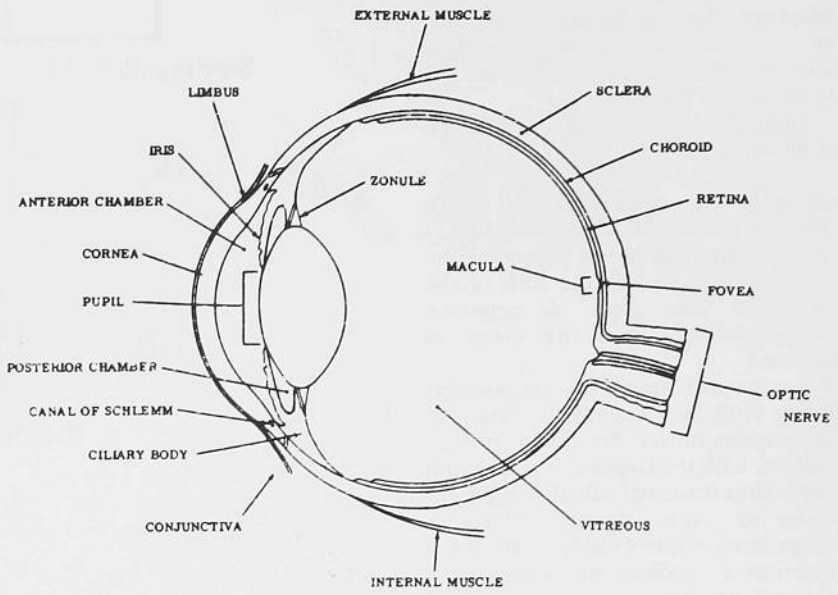
Suppose we want to know how many diopters of defocus correspond to one quarter wavelength of defocus for green light, 546nm? Combining the two expressions, we find very nearly that for ¼-wave of defocus or astigmatism:

$$\text{Diopters} = (\text{f/\#})2/(\text{eyepiece f.l.})2$$

For example, if the eyepiece has an EFL = 12.7mm (½") with an f/8 beam, ¼-wave of defocus corresponds to 0.4 diopter. With an f/16 beam, 1.6 diopters correspond to ¼-wave of defocus. This helps to explain why it's possible to focus more carelessly on refractors than reflectors (a dangerous generalization, of course).

The Human Eye

A telescope must fit its emerging light into an observer's eye, a difficult task sometimes slighted by the designer. It is a source of complaint with some eyepieces. Young people can focus from infinity to less than 100mm, or at least 10 diopters of accommodation. Around age 40, however, accommodation range



begins to wane and eventually vanishes, leaving us only with a depth of focus of about ½ diopter.

The aperture, or pupil, of the eye, is defined by the iris, and ranges from 2 to 8mm according to light level, taking from 5 to 10 seconds to span most the range. The retina takes much longer to adjust to changing light levels. The color balance or perception of the eye is altered by viewing bright or highly colored objects, and alone, the eye is a poor judge of color and brightness.

It takes about half a second for the eye to span its range of focus. Frequent refocusing is disquieting. Refocusing may lead to headaches if the observer must constantly accommodate for eyepiece astigmatism, field curvature, or defocus. Other eyepiece properties, such as an ill-defined exit pupil, cause similar discomfort.

The foveal region of the retina provides maximum resolution under moderately bright light conditions. It is said that the eye can resolve 1 minute of arc, limited by the size of the cones on the retina, but that black lines on a light field can be detected even when the width of the line is 0.5 second of arc. Of course, these lines are not resolved, but only detected.

If the resolution is 1 minute of arc, then the diameter of the Airy disk would be 2 minutes of arc by the usual reasoning; given the posterior focal length of the eye is 22.9mm, it takes a pupil 0.5mm in diameter to produce an Airy disk of this angular size. To produce such a small pupil with a telescope, we need to apply 50 power per inch of aperture to the telescope. As most observers know, this much magnification is seldom useful because atmospheric seeing precludes diffraction-limited viewing.

The diffraction-limited power is reached with an eyepiece whose focal length, in millimeters, equals half the objective's f/number. For an f/8 telescope, this requires a 4mm eyepiece. Of course, the exit pupil with any eyepiece is simply its focal length divided by the f/number of the objective.

The eye does not ordinarily focus beyond infinity. This produces some special problems when we deal with eyepieces. As we shall see, the sagittal focus of an eyepiece curves toward the eyepiece, while the tangential field curves away from the eyepiece. If we set our focus at the axial focal point, our eyes can accommodate for the tangential field points, but cannot focus beyond infinity for the inward-curving sagittal field. Some designs flatten the sagittal field, but this leads to twice the astigmatism, which is usually intolerable. Thus, we can either refocus as we require, *or* we can focus for the maximum sagittal field point, then let our eyes accommodate for the axial defocus as well as the tangential field curvature. Some of the new types of eyepiece will eliminate both field curvature and astigmatism so this problem will hopefully vanish.

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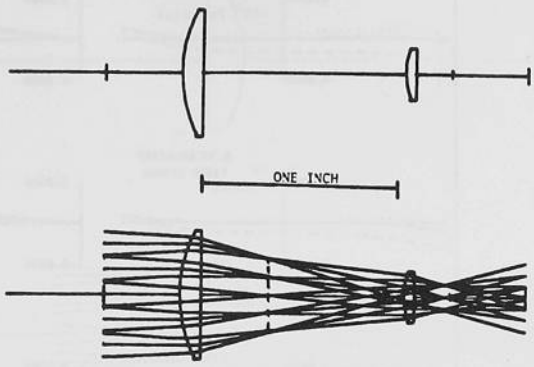
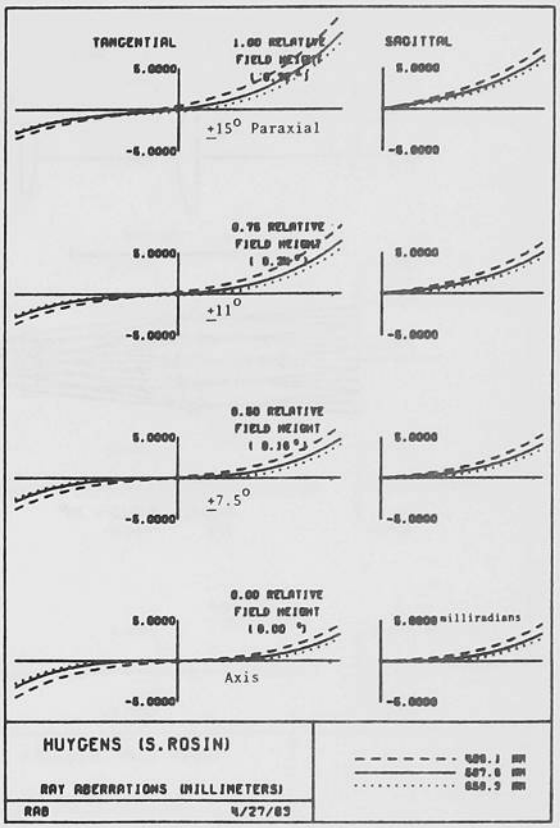
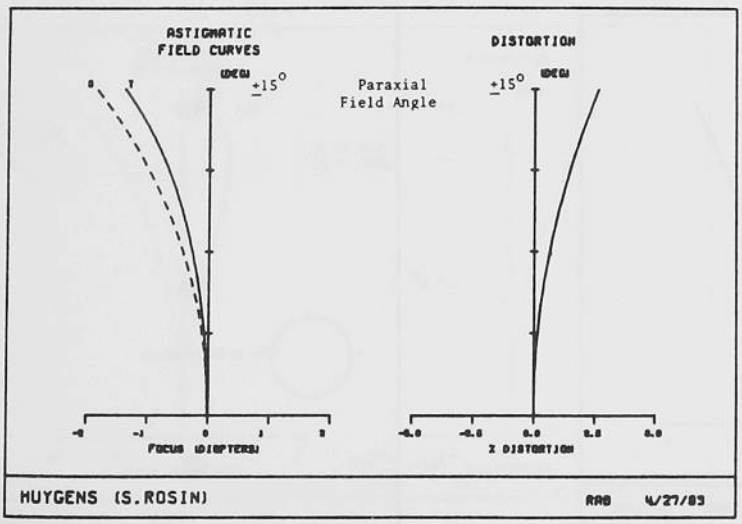
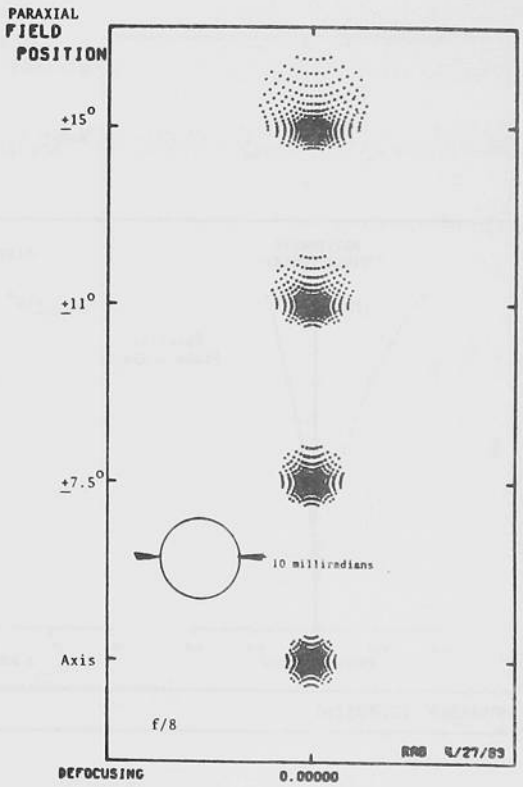


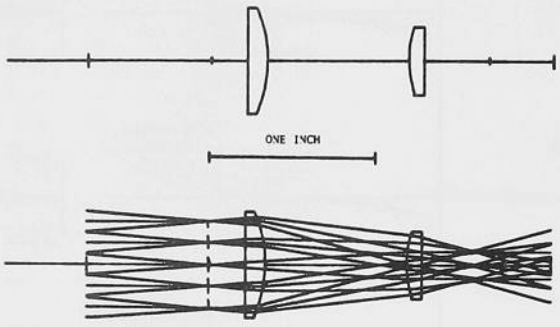
HUYGENS (S.ROSIN)
PARAXIAL FIELD = 30°
f/8



Huygens

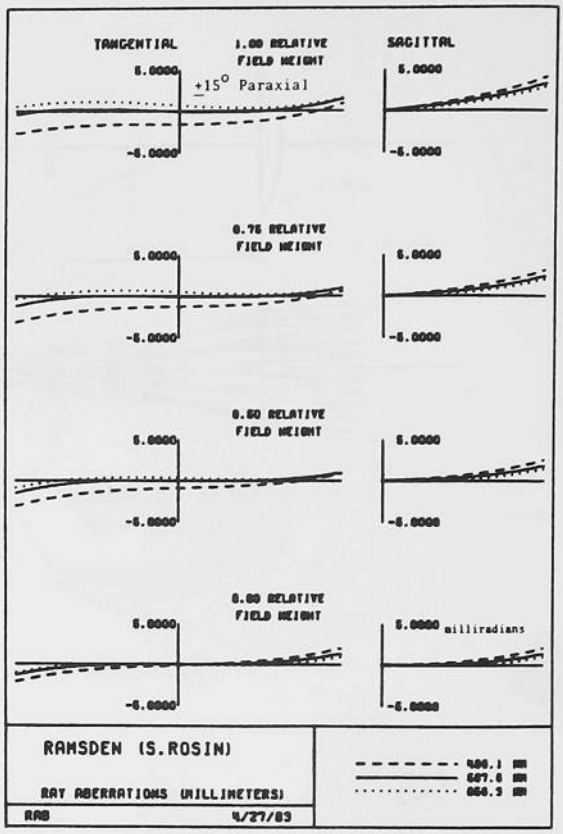




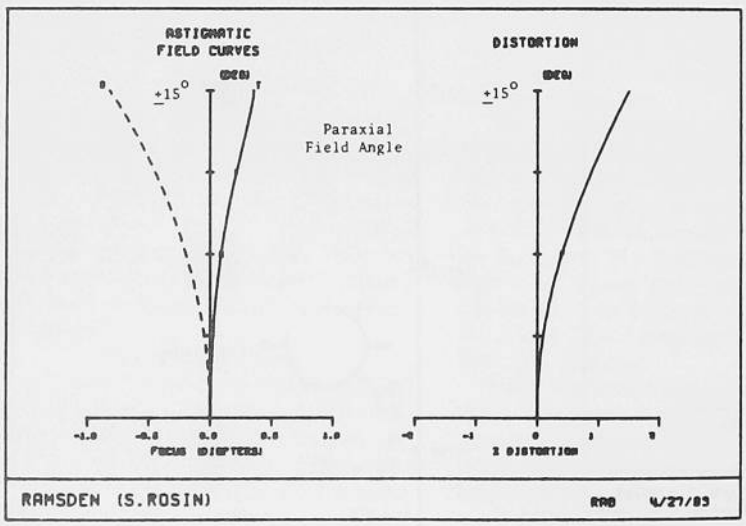


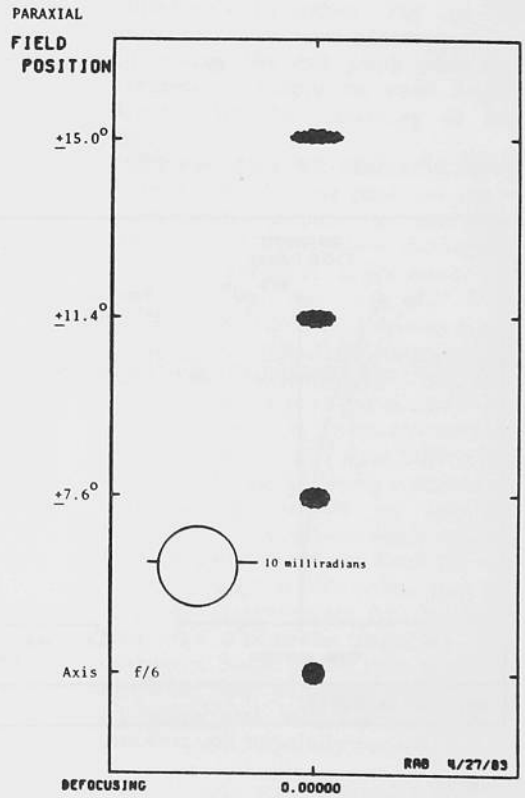
RAMSDEN (S.ROSIN)

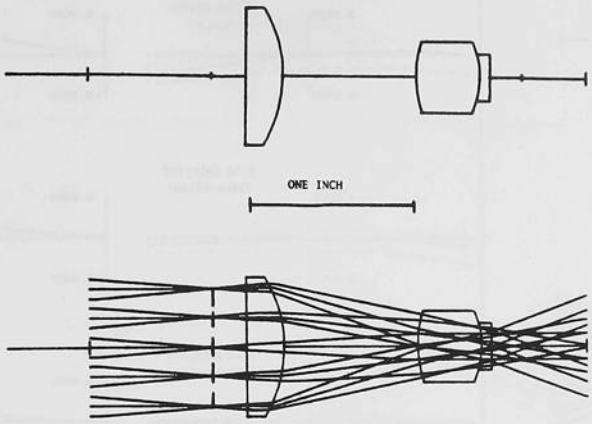
PARAXIAL FIELD = 30°
f/6



Ramsden

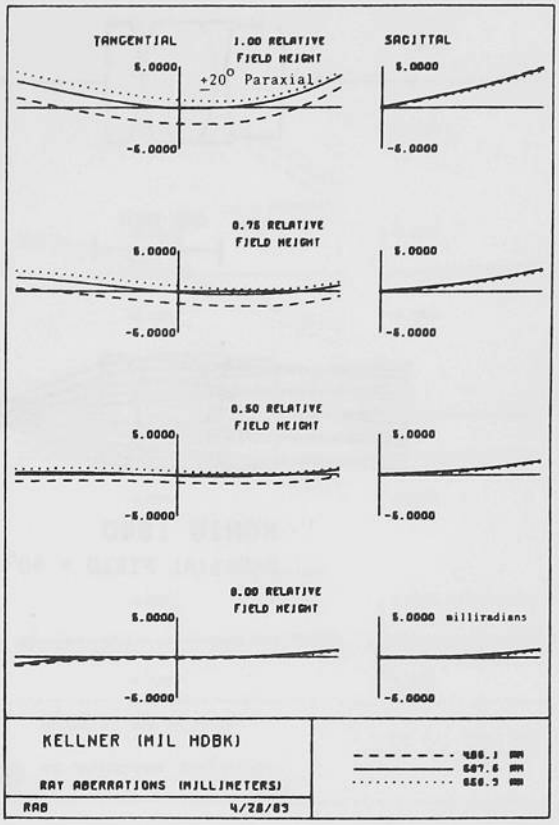




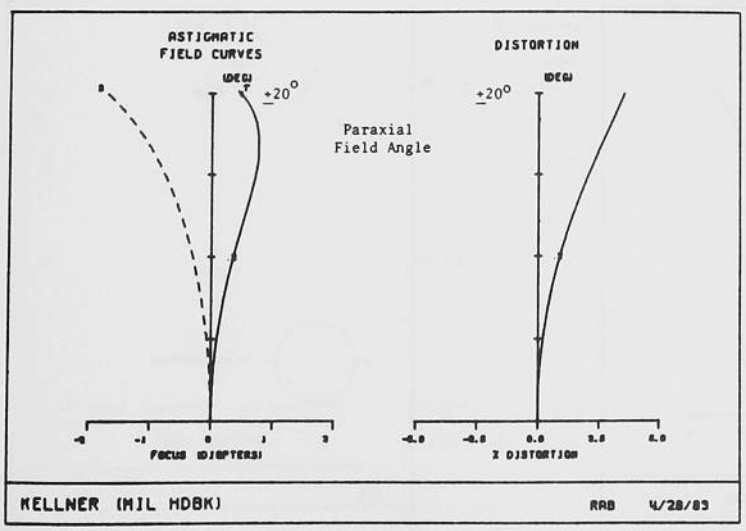


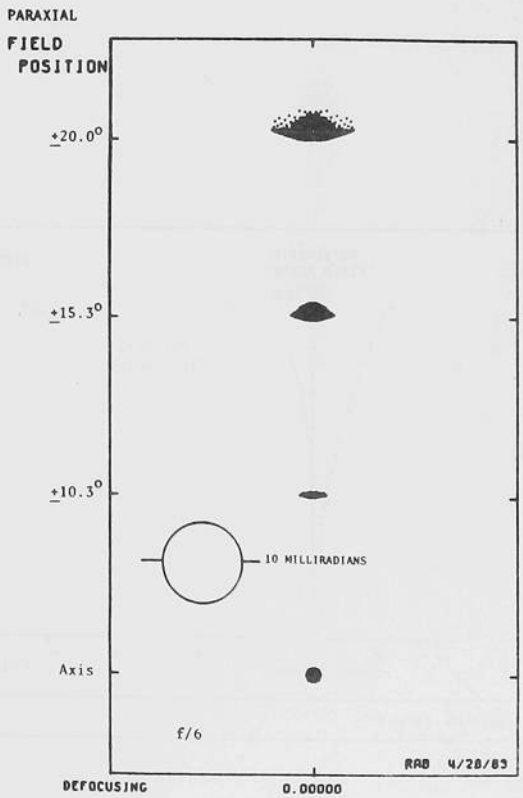
KELLNER (MIL HDBK)

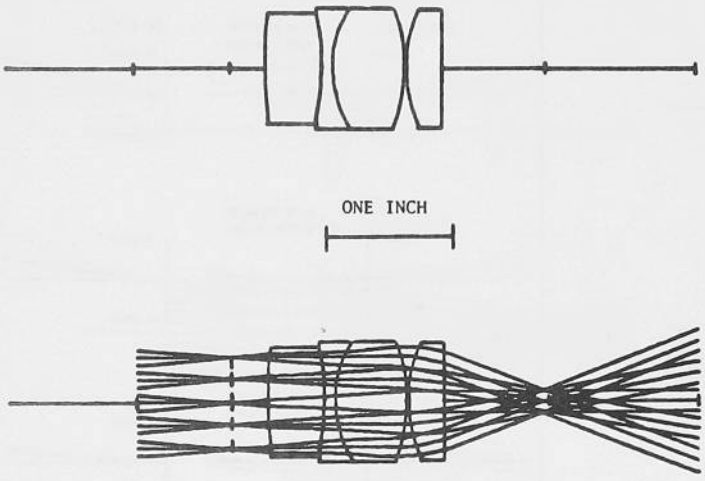
PARAXIAL FIELD = 40°
f/6



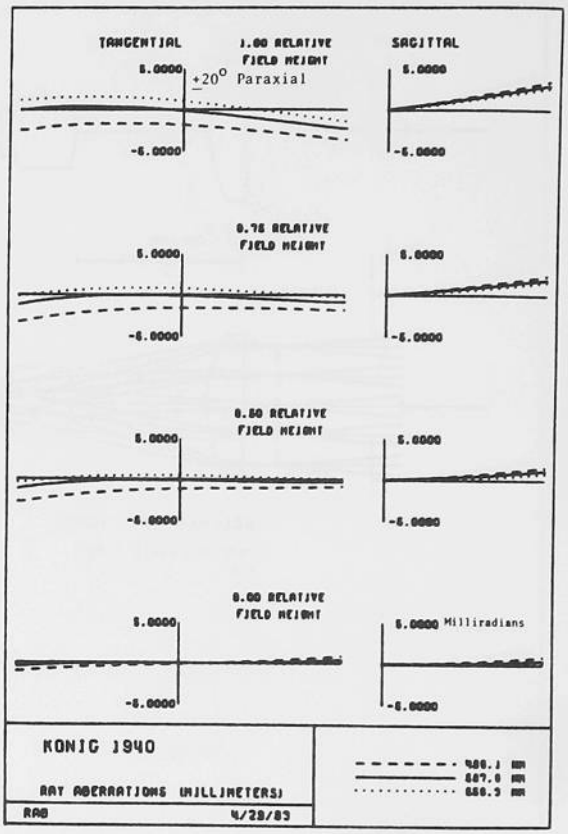
Kellner



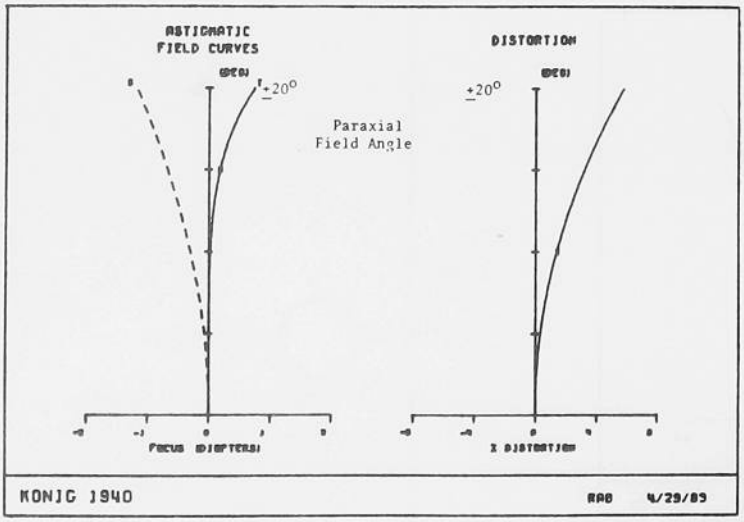


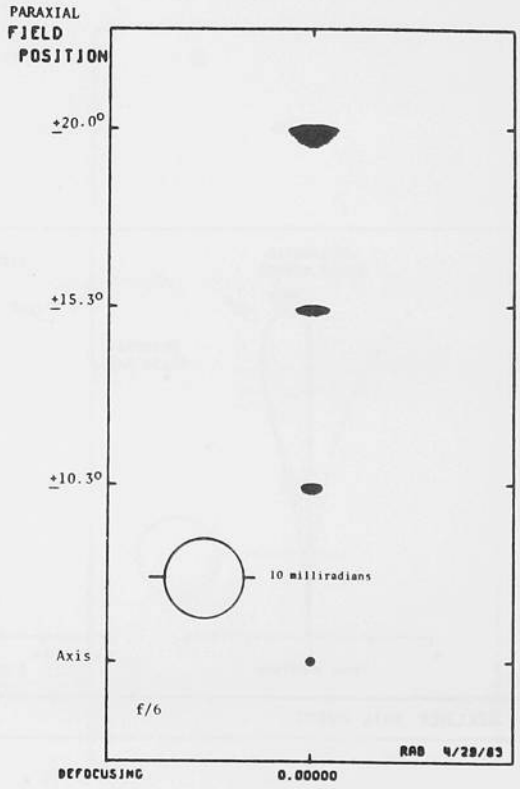


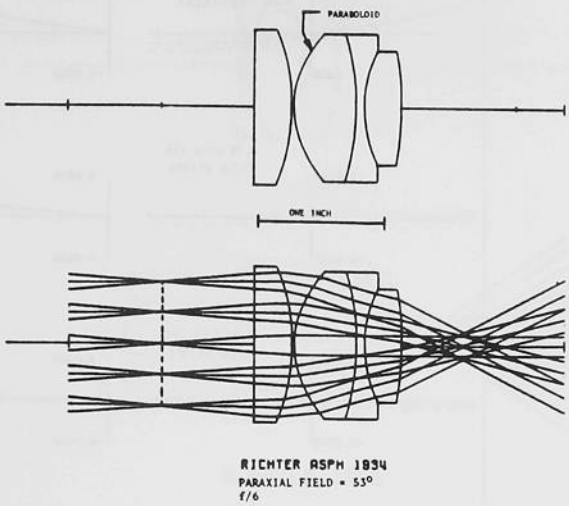
KONIG 1940
PARAXIAL FIELD = 40°
f/6

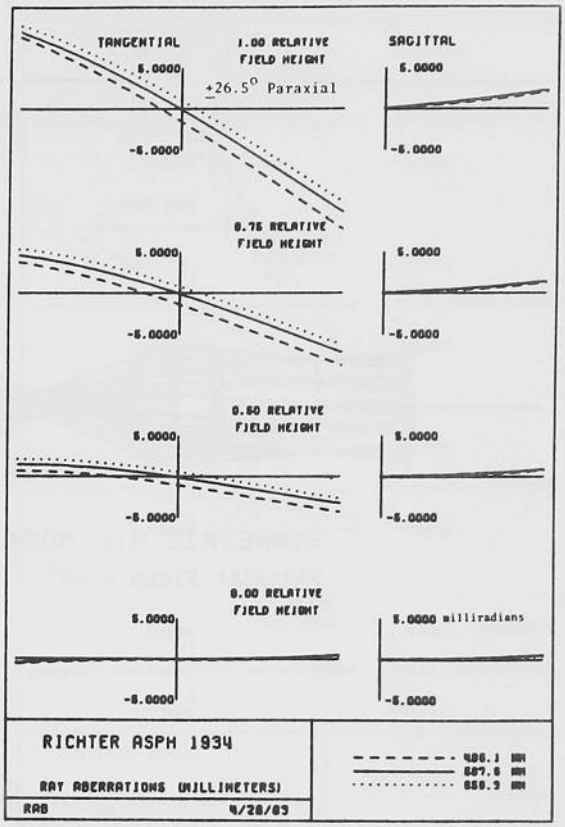


Konig









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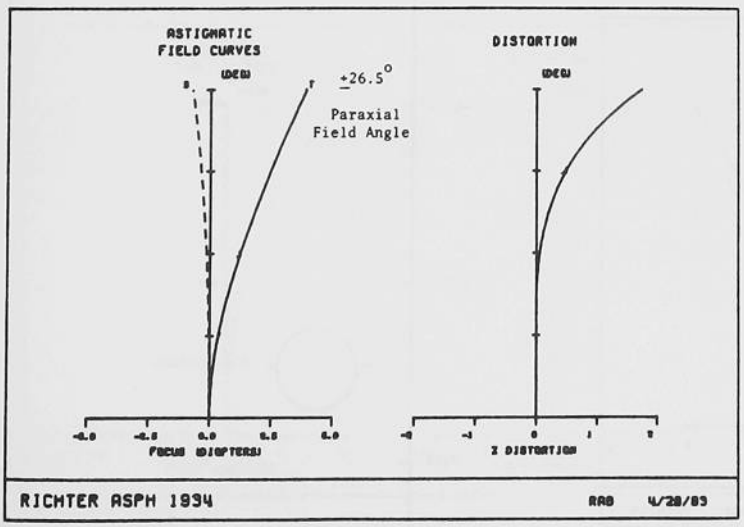
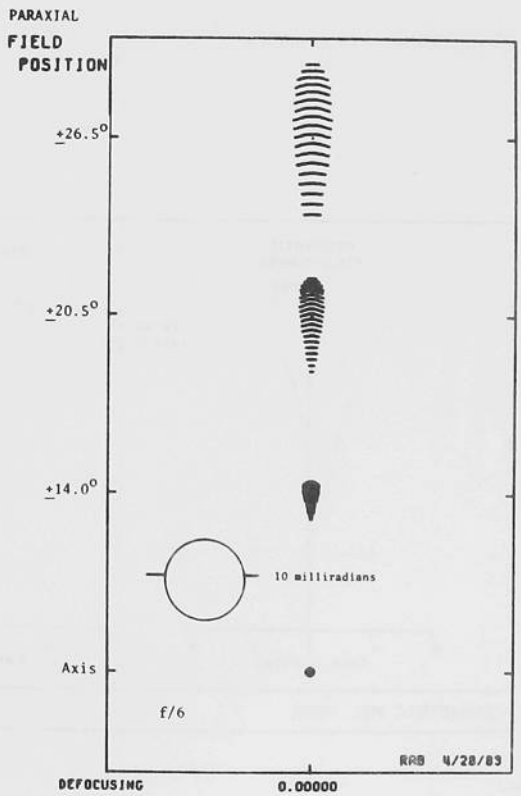
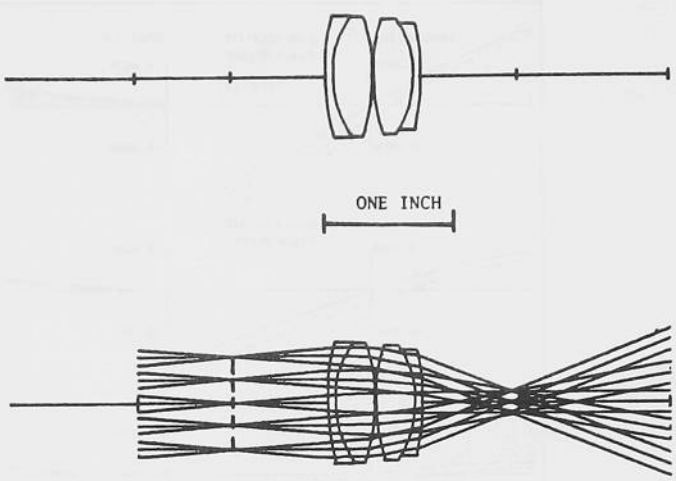
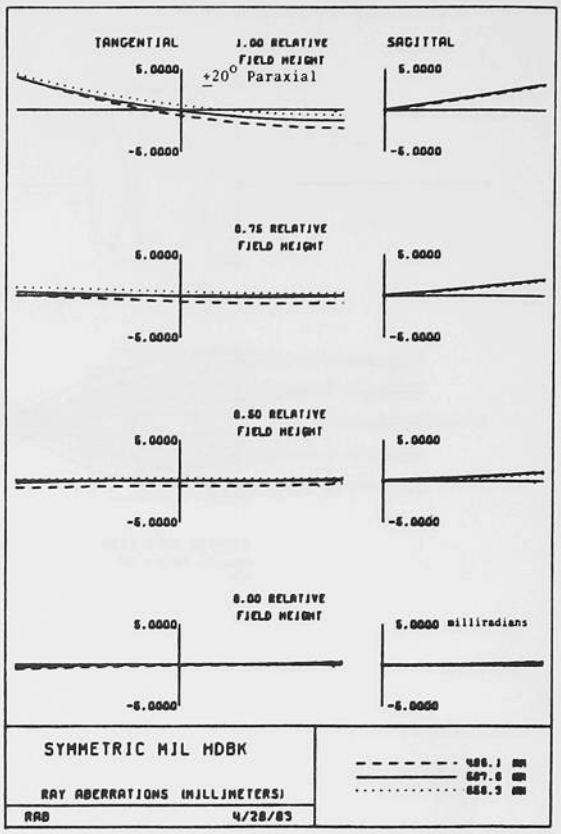


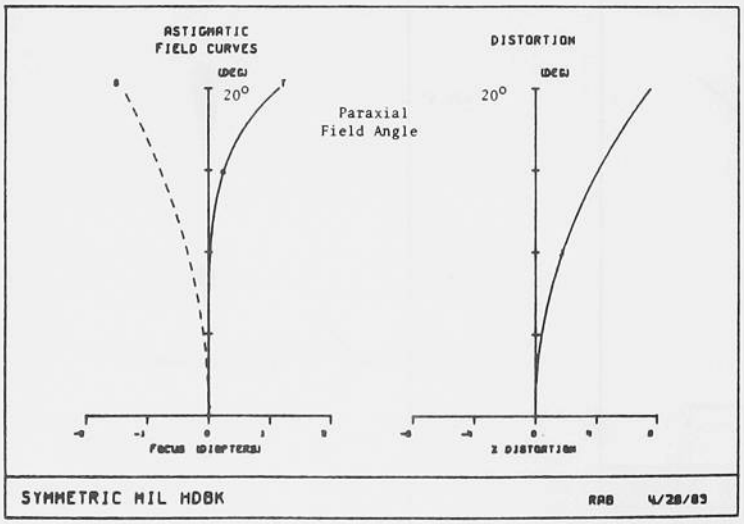


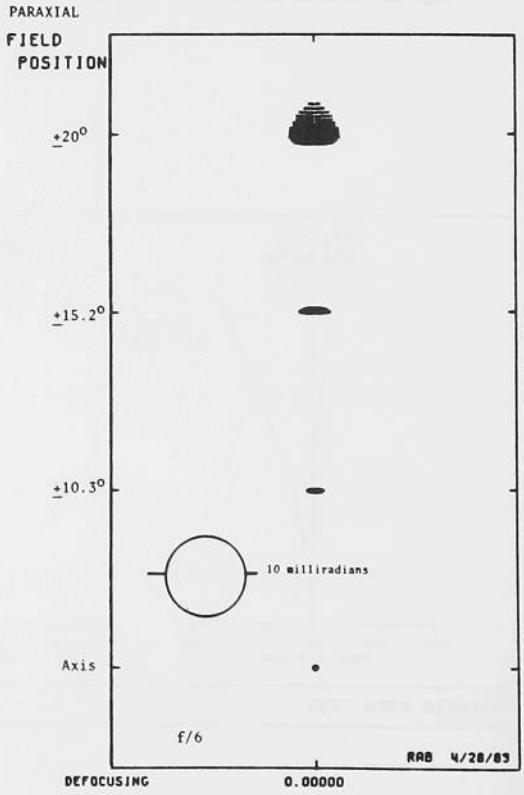


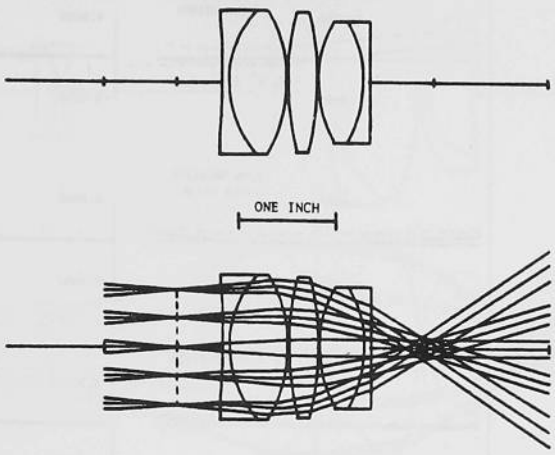
SYMMETRIC MIL HDBK
PARAXIAL FIELD = 40°
f/6



Symmetric

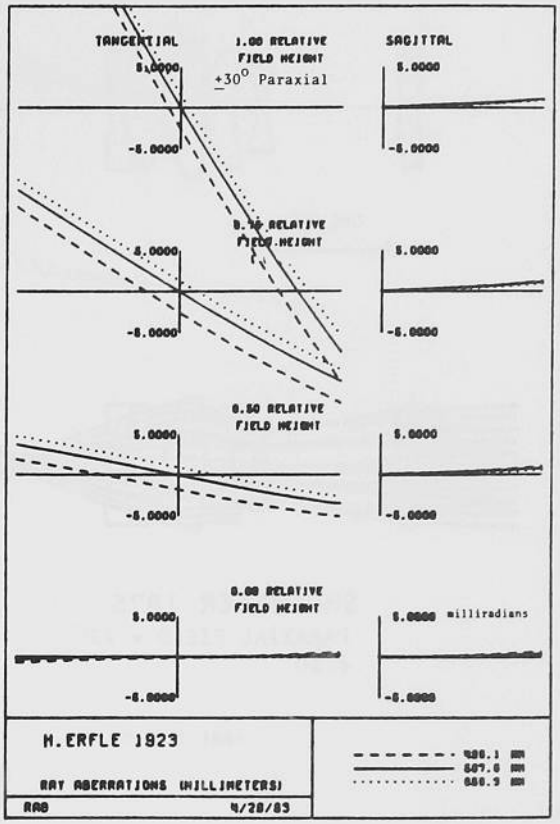




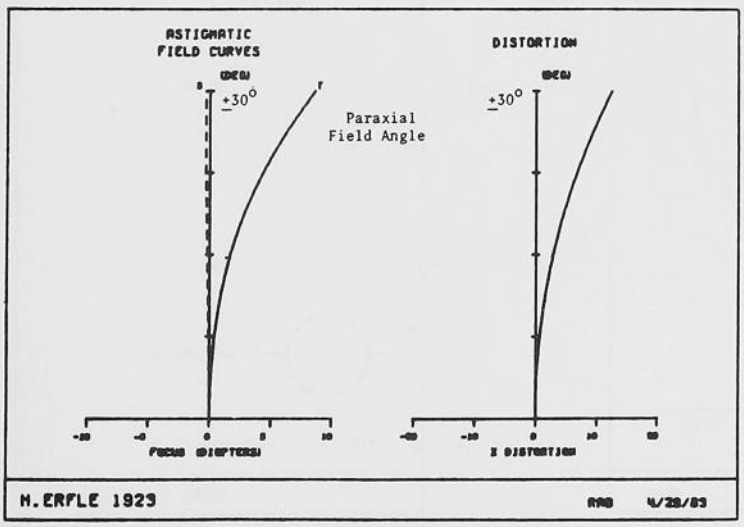


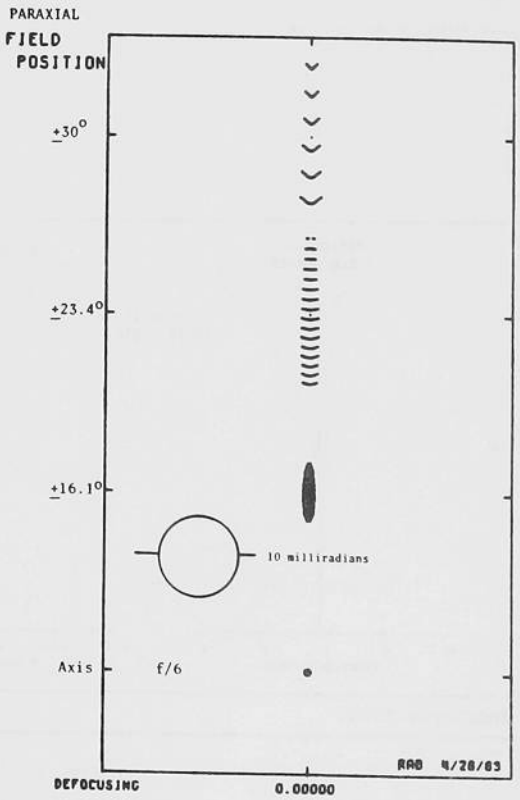
H. ERFLE 1923

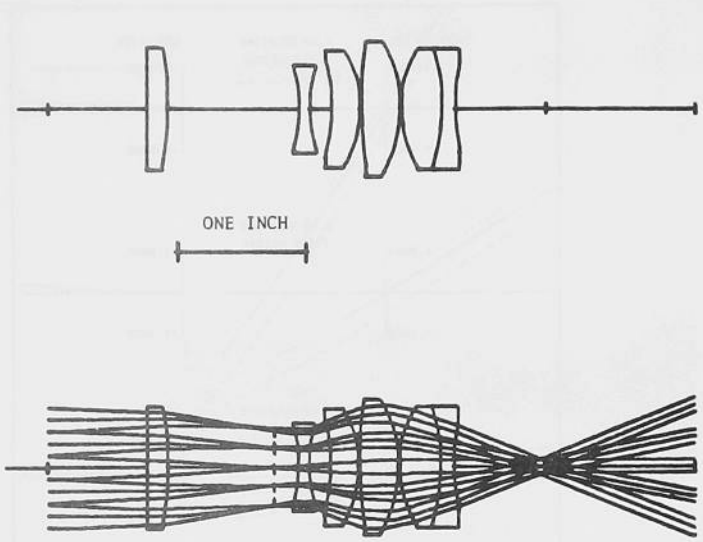
PARAXIAL FIELD = 60°
f/6



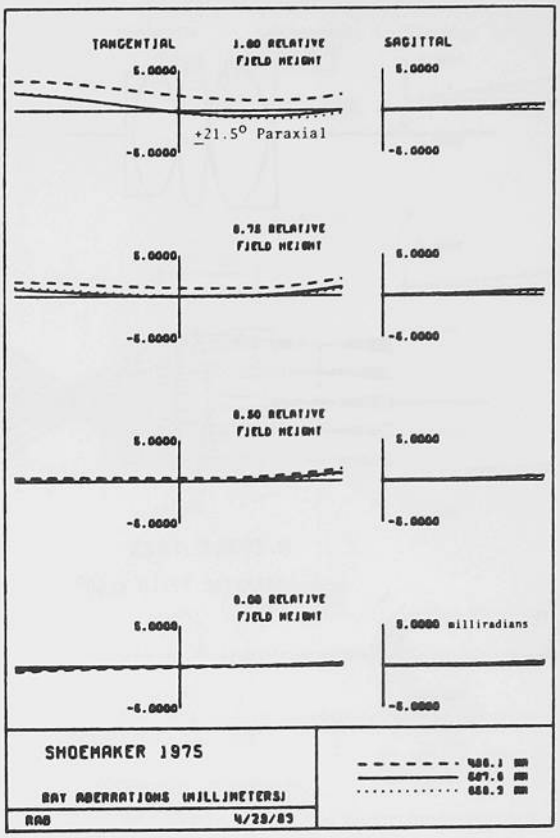
Erfle



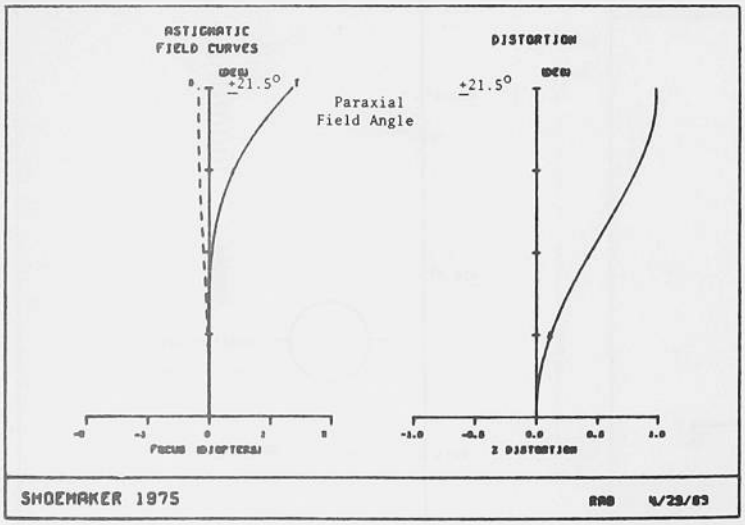


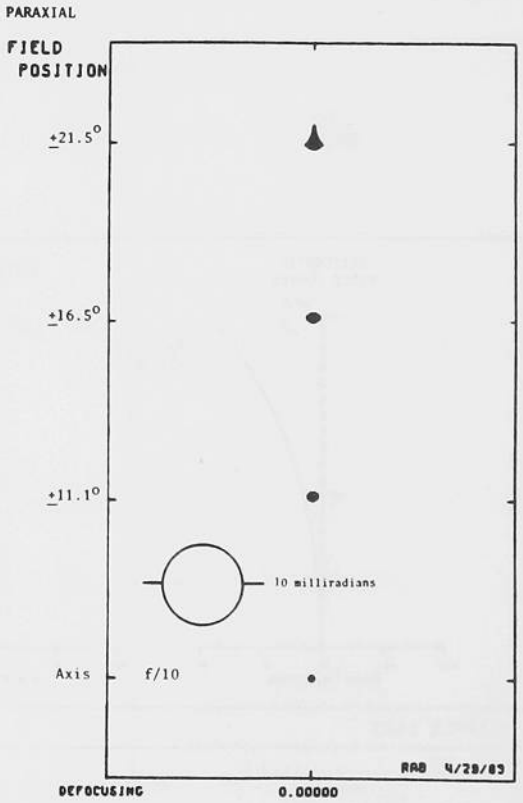


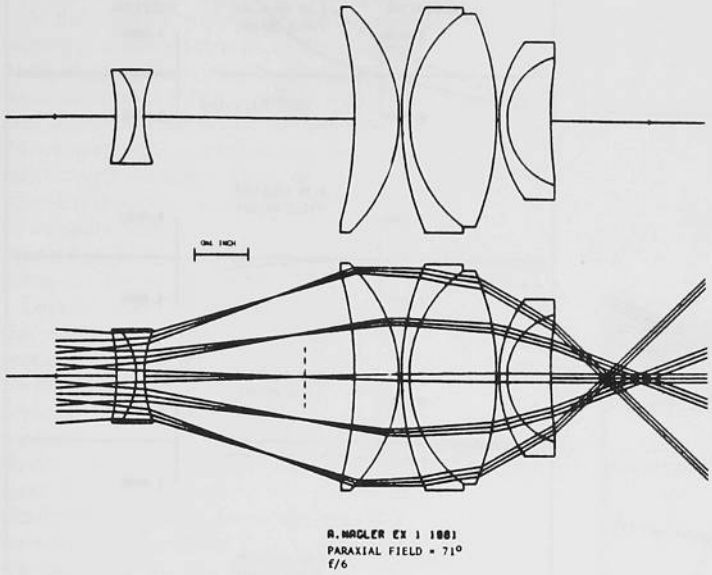
SHOEMAKER 1975
PARAXIAL FIELD = 43°
f/10

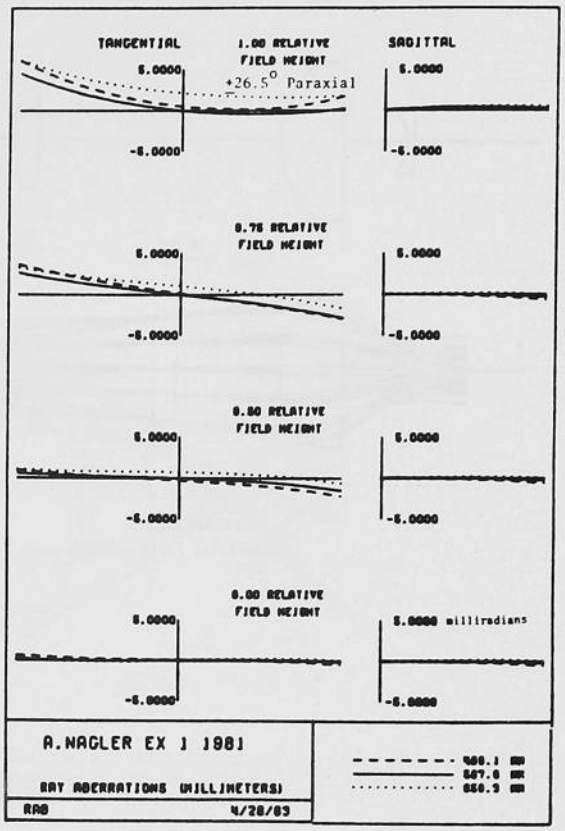


Shoemaker

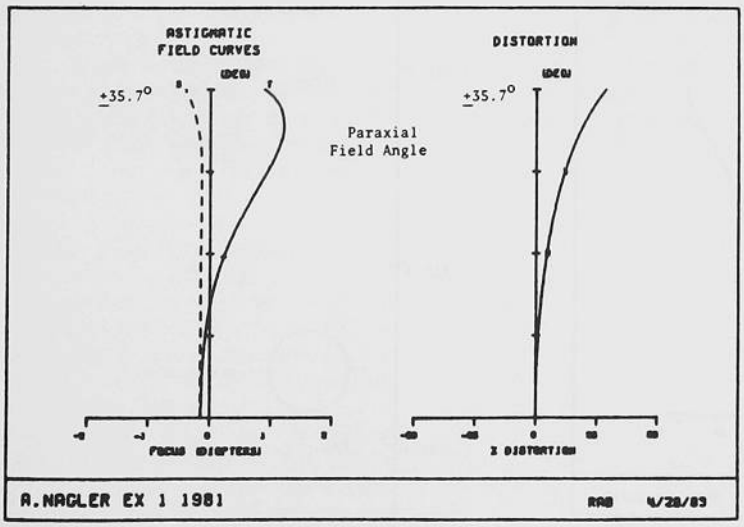


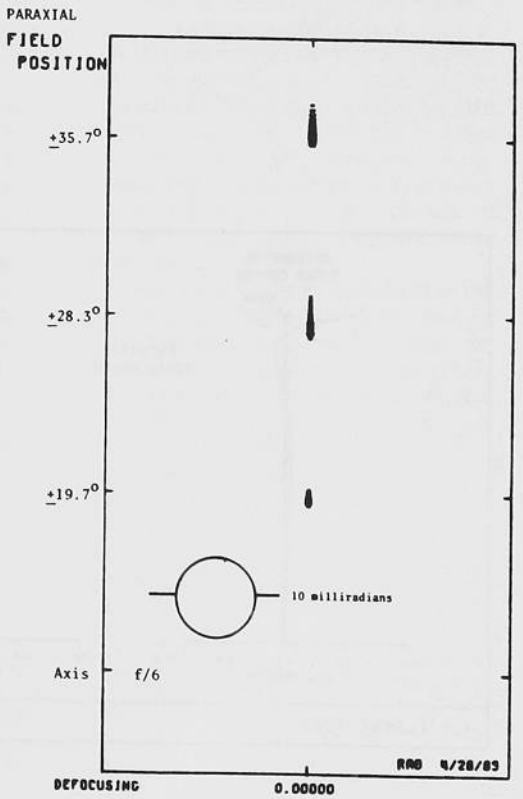


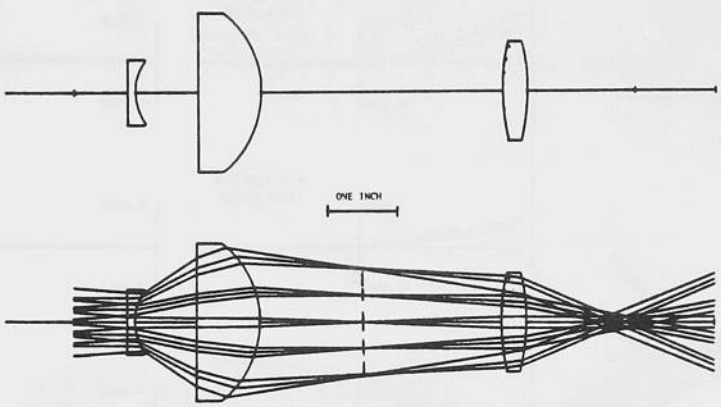

A.NAGLER EX 1 1981
PARAXIAL FIELD = 71°
f/6


TANGENTIAL
1.00 RELATIVE FIELD HEIGHT
+26.5° Paraxial
SAGITTAL
0.70 RELATIVE FIELD HEIGHT
0.50 RELATIVE FIELD HEIGHT
0.00 RELATIVE FIELD HEIGHT
5.0000
-5.0000
5.0000 milliradians
A.NAGLER EX 1 1981
RAY ABERRATIONS (MILLIMETERS)
RAB 4/28/83

Nagler

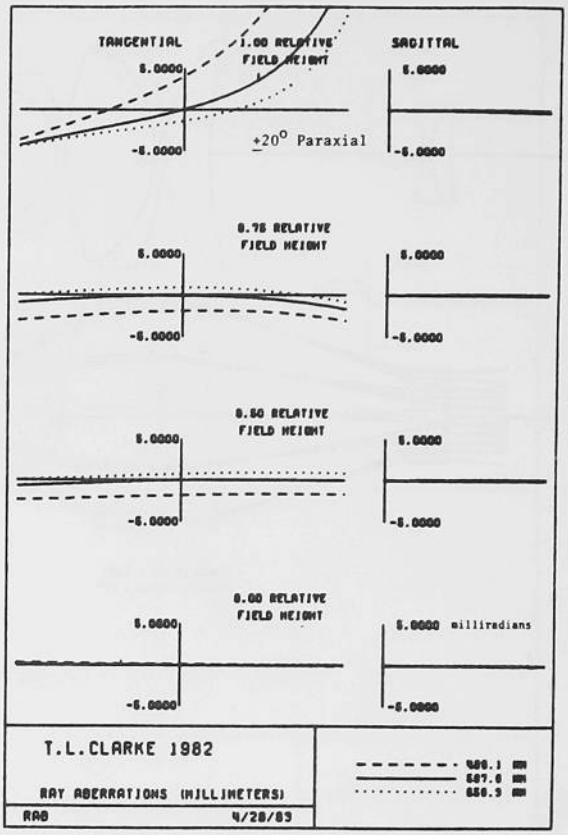

ASTIGMATIC FIELD CURVES
DEG
±35.7°
Paraxial Field Angle
DISTORTION
DEG
±35.7°
FOCUS (DIOPTERS)
% DISTORTION
A.NAGLER EX 1 1981
RAB 4/28/83


PARAXIAL
FIELD POSITION
±35.7°
±28.3°
±19.7°
10 milliradians
Axis
f/6
RAB 4/28/83
DEFOCUSING
0.00000

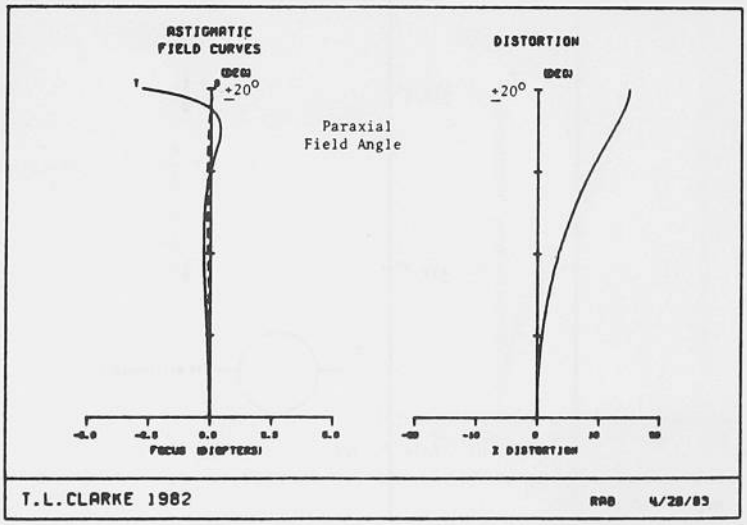


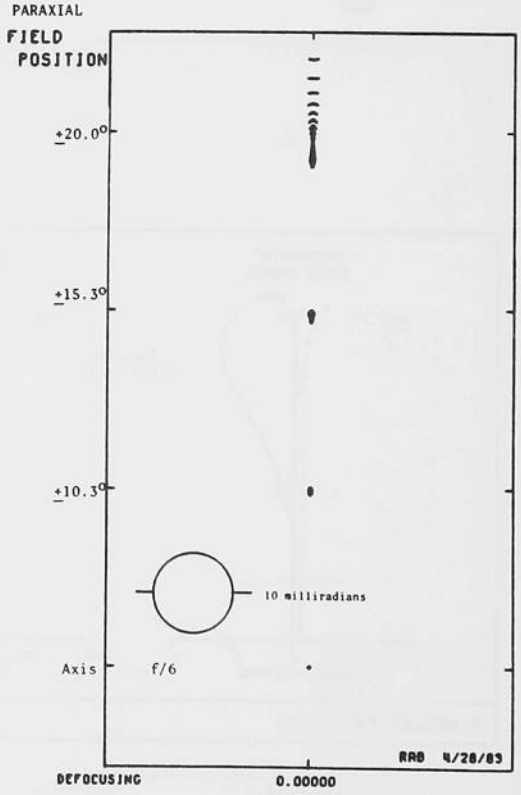
T.L.CLARKE 1982

PARAXIAL FIELD = 40°
f/6



Clarke





A Hierarchy of Eyepiece Designs

At the bottom of the hierarchy is the primitive Galilean eyepiece. The singlet positive magnifier is optically no more sophisticated, but it is a better solution and therefore lies higher on the chart. As we ascend the chart, things become more sophisticated, although certain adjacent levels are so similar in degrees of freedom that it becomes a matter of opinion which should be higher or lower on the chart.

Levels V and VI probably represent the minimum complexity at which the complete correction of aberrations is *theoretically* possible. Since even complex lens systems can be reduced to a smaller number of equivalent thin lenses that serve a logical function, we have done this to show the essential similarities between some designs. The lens designer basically knows what the components do, and therefore he can better understand the potential quality of an assembly of such components. In the hierarchy, levels VII and higher contain enough redundancy that a very high degree of optical quality is possible. It is possible to exploit the extra degrees of freedom in the design — not for perfection, but for flexibility — if a wide field or some other purpose suits the designer. The current state of the art in astronomical eyepiece design seems to be level IX.

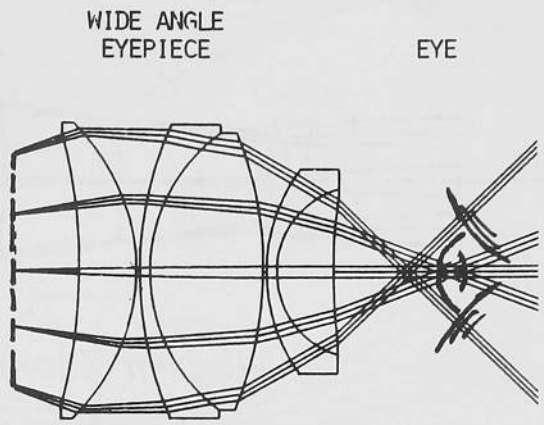
Special Considerations

An optical designer must pay particular attention when designing complex and highly corrected new eyepieces. Problems previously unknown have arisen and these have surprised even seasoned professional designers.

First, with a wide-angle eyepiece, it is particularly important to reduce or correct the spherical aberration of the exit pupil. This is, in fact, not inconsistent with obtaining a highly corrected image.

A problem that the writer stumbled on was spherochromatic aberration of the exit pupil. The effect of this is that while the spherical aberration appears to be corrected, it is in fact only zero for one wavelength. If it is too severe, images have unreal and fleeting chromatic hues. It can be severe enough that a design is intolerable.

Experienced microscope designers have found that in practice it is better to have the spherical aberration of the exit pupil slightly undercorrected, and that it is definitely bad to have it overcorrected. While no theoretical cause has been defined for this, it may have to do with the fact that the cornea is separated from the pupil and may add to the overcorrection designed into the eyepiece.



Spherical aberration of the pupil means that eye must move in and out to see entire field of view. When the eye becomes decentered, this results in the kidney bean effect.

We often wonder what we could do if we could manufacture aspheric lenses cheaply. This writer's experience is that some designs of exceeding simplicity coupled with extraordinary monochromatic quality can be achieved with aspheric lenses. The problem of color correction in an aspheric design is trickier than with an all-spherical design, but fortunately color is not the worst of the problems we face. The prior art seems to have used aspherics to reduce or correct for distortion. Their use to correct for pupil aberrations is almost obvious by inspection. The writer finds that it is more productive to let a design go where it wants to, rather than using the aspheric with too particular an end in mind. Perhaps some enterprising talent will find a way to produce aspheric lenses cheaply, even though private industry has failed at this for decades.

Since many of the advanced designs are negative-type eyepieces, we cannot place a field stop out front, but rather must place it inside the eyepiece. To have the field stop "look nice," lateral color from this point on to the exit pupil should be minimized, if at all possible. This is purely an aesthetic point. For photographic purposes, there is no need for the field stop since the camera format will usually be the limiting field aperture.

In a negative eyepiece, odds are the field or reticle plane will not be flat, but curved. This would be a problem for military optics, but is generally not a problem for astronomical eyepieces.

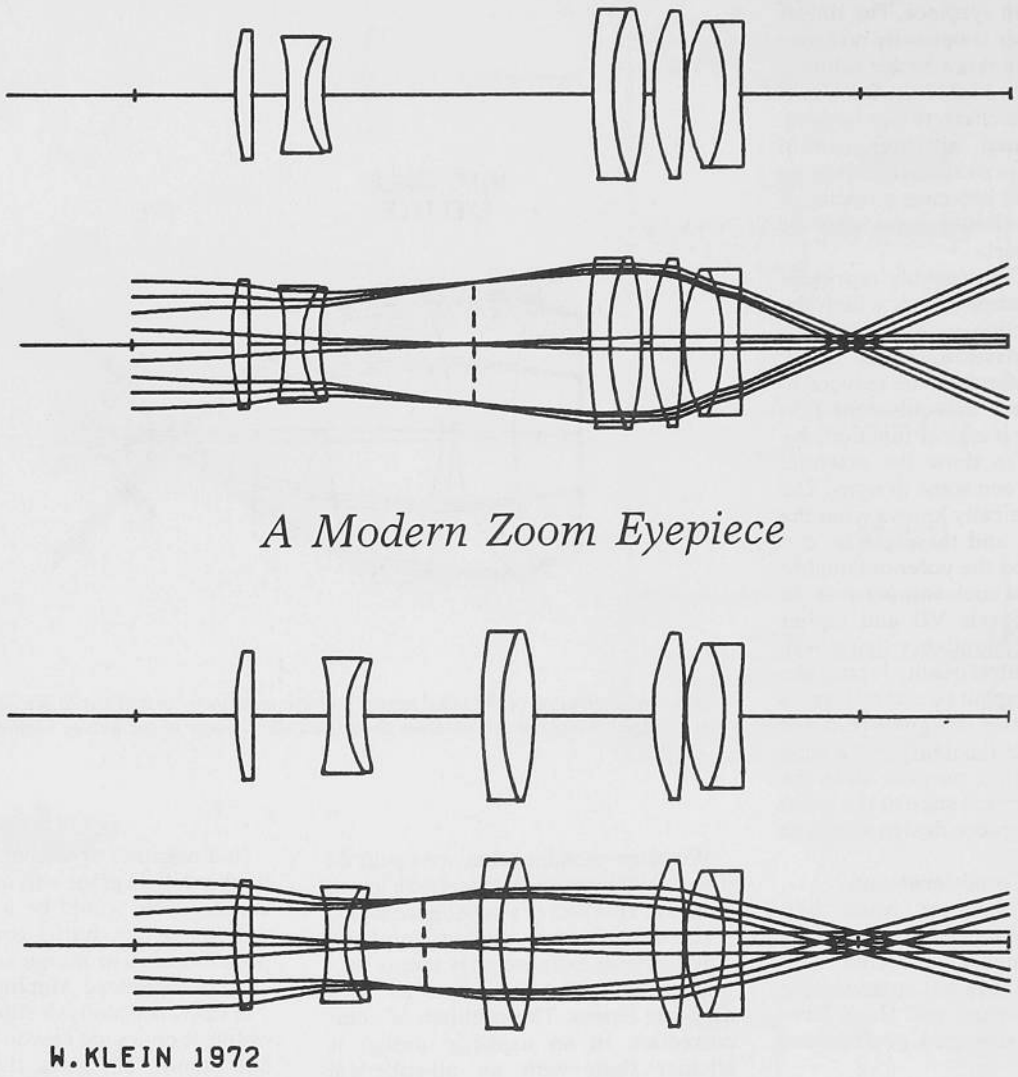
Eyepiece Mechanics

A tolerance analysis shows that most eyepiece optics are easy to grind, polish, and mount. The glass, though, should be free from defects that will be large relative to a 0.5mm diameter pupil. Should an eye lens become scratched or pitted, the amateur can resurface it himself without altering the performance.

Some manufacturers assume that the user will have perfect vision; designs that have a nice amount of eye relief are spoiled by eye positioning sleeves. If you want such optics badly enough, remove the lens elements, chuck it up, and turn down the sleeve.

A scummy surface on an eyepiece will cause "haze" in the image; a pronounced blemish will diffract like the spider vanes in a reflector. The amount of diffraction depends on the fraction of the exit pupil obscured and the shape of the obstructions. It is also worth pointing out to anyone who wears glasses that the glasses become part of the optical train, and you really ought to clean the lenses before doing any serious observing.

The problems with deficient, usually



A Modern Zoom Eyepiece

cheap, eyepieces seems to lie mainly with poor coatings and unsatisfactory lens barrels. A ghost image that is nearly in focus and chases the central image is unacceptable, yet such ghosts are not uncommon in cheap eyepieces. If the lens barrel, prior to the field stop, is not properly treated, it will funnel out-of-field image light into the desired image. Some eyepieces are not worth trying to salvage. Where you draw the line depends on the thickness of your wallet, or your desire for excellence.

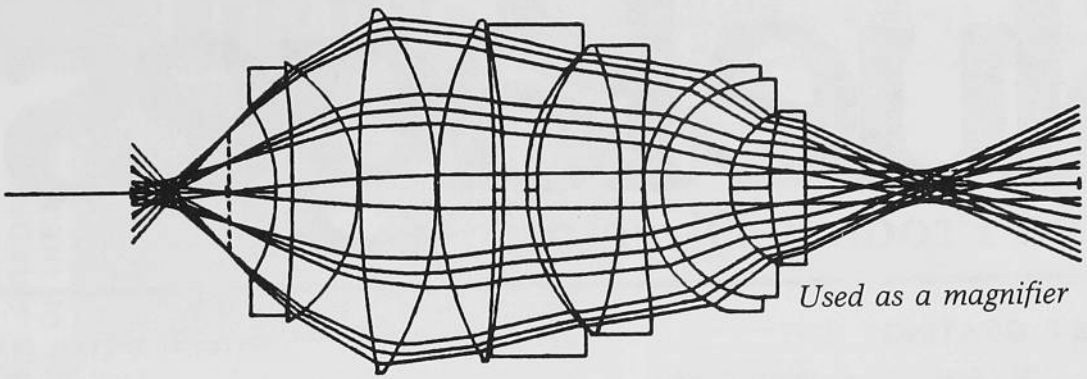
Although government surplus optics are long since a rarity, some manufacturers will dump surplus eyepieces, probably leftovers from image intensifier projects. These appear to be dandy eyepieces, big and awesome in outward appearance — but they were designed to be magnifiers for small phosphor images, and were color-corrected for green light. They may or may not be corrected for lateral color, depending on the specific application for which they were used. The biggest problem with many of them is that they are useless for astronomical purposes because the exit pupil lies inside, rather than outside, the eyepiece.

Eyepieces for daytime use, or for use in an illuminated environment such as an aircraft control tower, require special care. The external surface of the eyelens should not be plane because out-of-field reflections will be in focus and therefore distracting. Neither should this surface have a radius equal to twice the eye relief, for then it will re-image eyelashes and facial detail, which is likewise distracting. The ideal surface is several diopters convex — which may not be compatible with some optical designs — but we must cope with it as best we can by using high efficiency antireflection coatings.

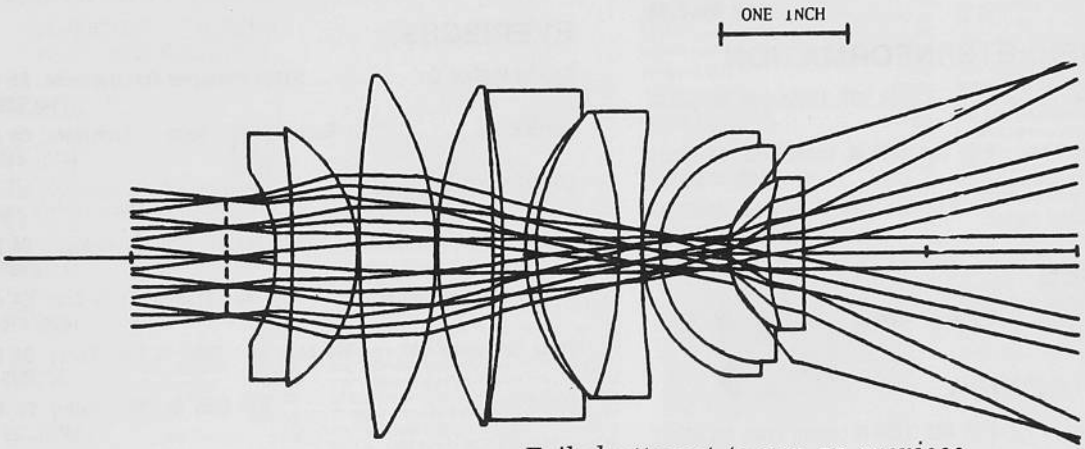
Optical Designs and Analyses

The designs analyzed in this article were taken from a variety of sources, from books on optics to the original patents. Some of the eyepieces were intended for use with microscopes and instruments other than astronomical telescopes, so that pupils and f/numbers are presumptuous.

I have chosen an entrance pupil located 48″ to the left of the eyepiece focal plane, which then is followed by the eyepiece, proceeding to the exit pupil at the extreme right. Field angles were usually in accordance with specifications accompanying the design. It is important to realize that all field angles and speeds are Gaussian, that is, numbers based on paraxial performance; the effects of distortion



Used as a magnifier



Foiled attempt to use as eyepiece

should be borne in mind. F/numbers are shown on the plots.

Universal designs are difficult and probably unnecessarily costly and complex for half the potential customers. Things that can be accomplished with high f/numbers, such as distortion correction, require undue complexity at low f/numbers. Therefore, it seems likely that specialization will remain with us.

The eyepiece picture is drawn twice, once without rays to show the geometry of the design, and again with rays to show how the exit pupil is formed. If the exit pupil is not well defined, the eye cannot accept all the light from all the field angles at once. This leads to a need to keep moving the eye in and out, and to keep the eye well-centered, or certain peculiar vignetting and obscuring effects (categorized as kidney beaning) occur.

Tangential and sagittal focal curves are drawn, as well as curves for distortion. When distortion is positive, objects become overmagnified toward the edge of the field. The precise tangential and sagittal curves will depend on the residual aberrations and the exact eye relief; these curves cannot take such variations into account, but they are representative.

Spot diagrams are usually familiar to all. A scale marker in milliradians shows the blur size. A milliradian is (57.3/1000) degrees, or about 3.44 minutes of arc. The spot diagrams are shown for a single wavelength of light in order to avoid confusion from chromatic aberration which may be corrected in most good designs.

Finally, a transverse ray aberration plot in three wavelengths and at several field angles enables an optical designer to infer the state of optical correction for any position of the eye capable of receiving light from the telescope.

These plots were computed using Optical Research Associates Code V computer program. Computer time was kindly donated by my colleagues at the Hughes Aircraft Company's Tucson Engineering Laboratory.

Conclusion

Modern eyepieces will be designed on the computer, and as we've seen, there are a lot of things for the designer to keep track of. The consumer must think seriously about how important the quality of the eyepiece is to him. How much is he willing to pay for an eyepiece? Does the tail wag the dog?

What about the future of complete telescope systems? Perhaps the eyepiece and the objective system should be integrated and cross-corrected. This might lead to some novel and important new configurations. It seems to this writer that such systems should incorporate a zoom section so that the instrument will be complete, dust-sealed, and capable of serving without need of attachments to his telescope. It is not out of the question to expect a range of magnification of 10:1 or even 20:1. This would allow a telescope to serve as its own finder. I'm sure the readers of TM will add their own ideas to the wish list, and the number of optical designers willing to participate in designing first-rate astronomical eyepieces will continue to grow.

R.A. Buchroeder, Ph.D.
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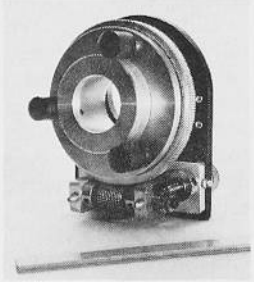

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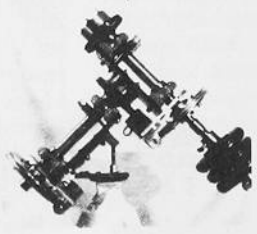

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ASTROPHOTO OF THE MONTH

Crab Nebula M-1 in Taurus. The Crab Nebula is seen best visually with a LUMICON DEEP-SKY Filter. Photo by David Healy using a LUMICON Giant EASY-GUIDER and LUMICON hypered 2415 film. 33 min. exposure, Celestron-14 at f/6.

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48mm for 2" eyepieces	$119.50	$99.50
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Set, 1¼" UHC & Deep-Sky Filters		$119.50
Selected premium filters		add $20

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Yields spectacular contrast gains in B&W photography with telephoto lenses. Yields pinpoint star images. Superb with hypered 2415. For color, use the Minus Violet (MV) Filter.

Specify Lens Size	H-Alpha	(MV)
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52, 55, 58, 62mm	$39.95	$29.95
67, 72, 77mm	$46.95	$39.95
82mm	$49.95	

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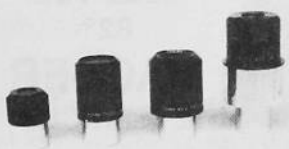

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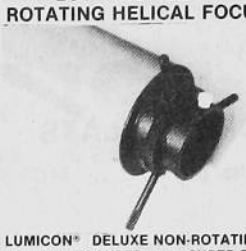

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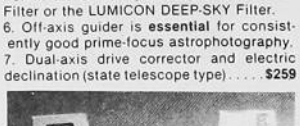

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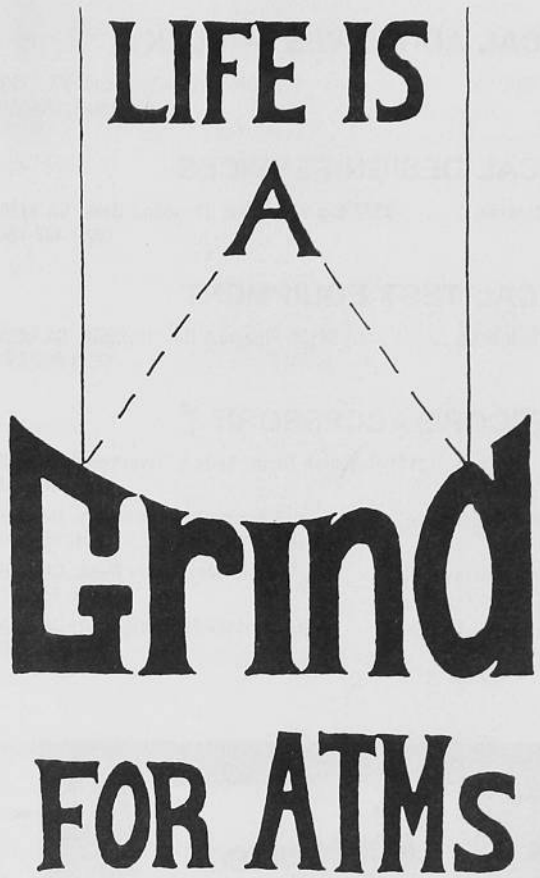

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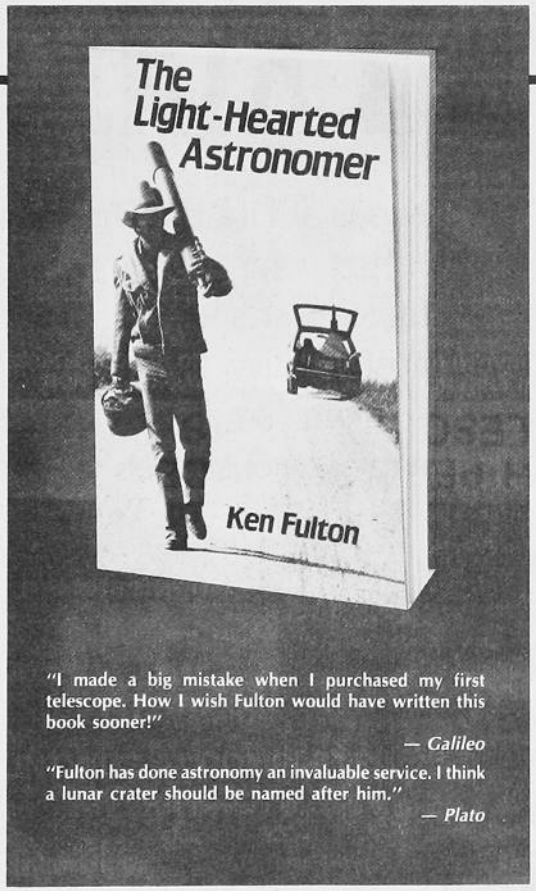

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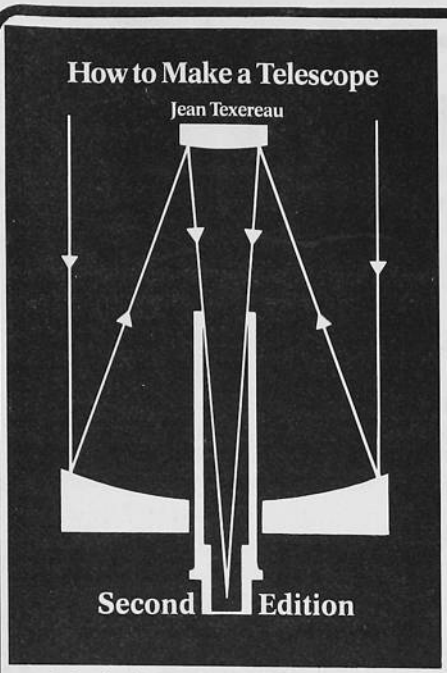

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BY
JEAN TEXEREAU
TRANSLATED AND ADAPTED BY
ALLEN STRICKLER

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FOREWORD to the Second English Edition, Richard Berry
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From the Foreword to the First Edition
Albert G. Ingalls
Editor: *Amateur Telescope Making I, II, and III.*
Scientific American magazine

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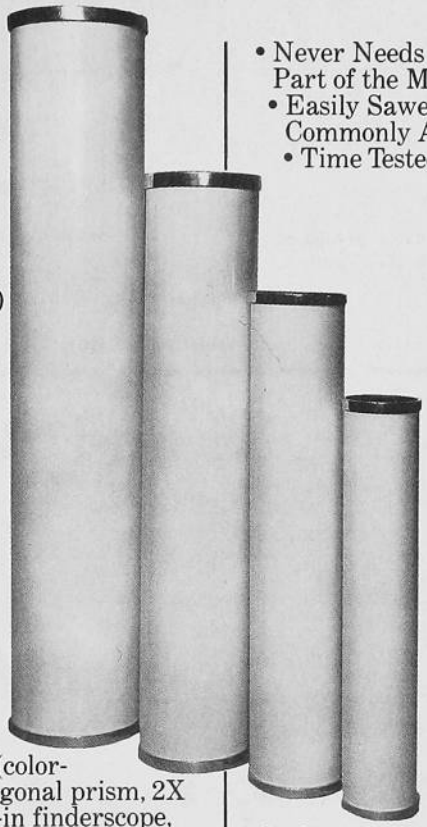

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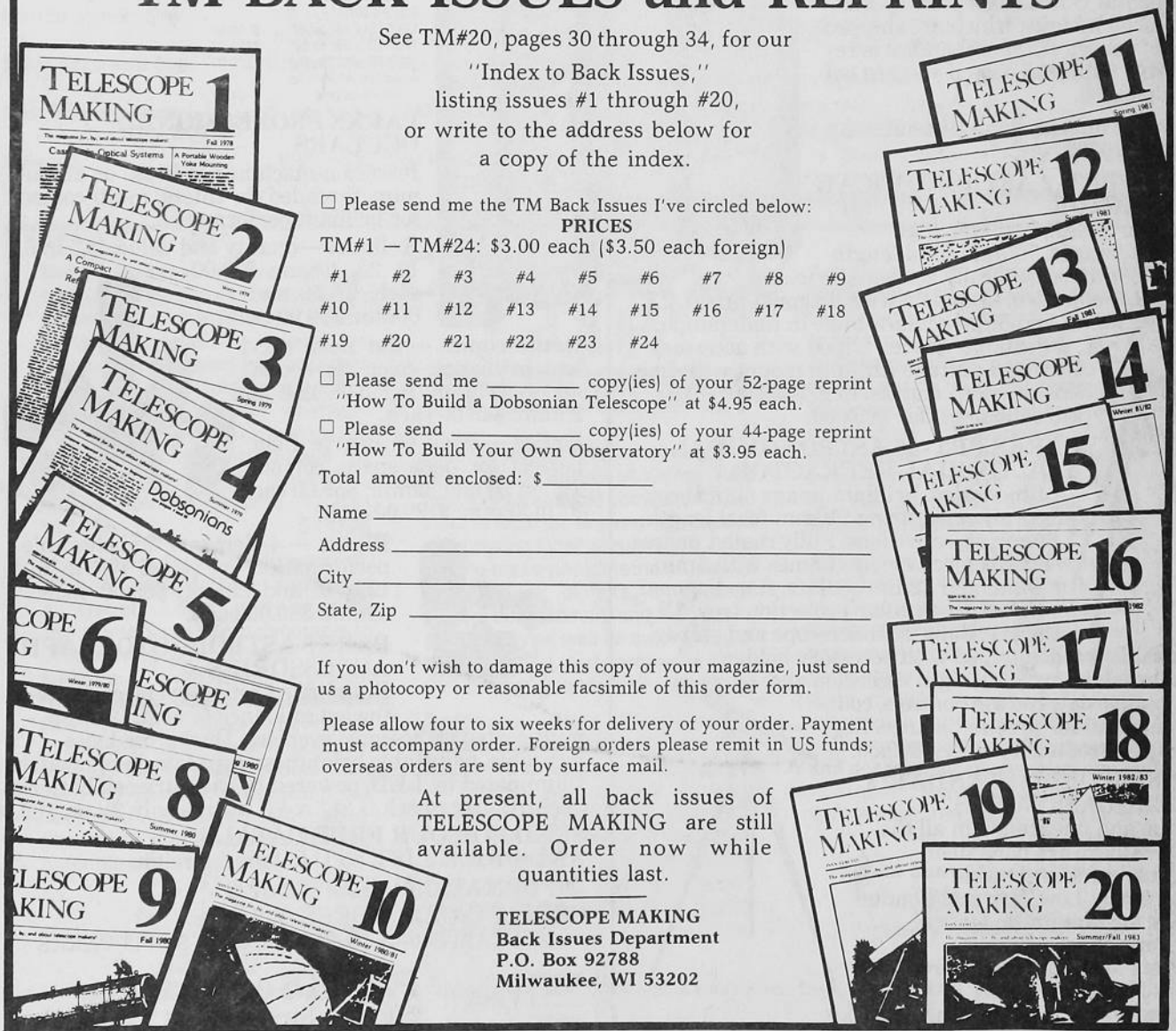

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